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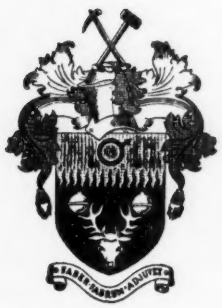

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ABBREVIATIONS AND SYMBOLS

Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled ; alternating current
A.H.	air-hardened
amp.	ampère(s)
amp.hr.	ampère-hour(s)
approx.	approximately
at.-%	atomic per cent
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade; Celsius (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dia.	diameter
dil.	dilute
dm.	decimetre(s)
e.m.f.	electromotive force
e.v.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kg.	kilogramme(s)
kg.cal.	kilogramme-calorie(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units
l.	litre(s)
lb.	pound(s)
L.F.	low-frequency
M	molar (solution)
m.	metre(s)
m.amp.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum ; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth ; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc ; foot (feet)
″	second of arc ; inch(es)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\simeq$	approximately equal to
$\propto$	proportional to

Unless otherwise stated above, the symbols given in the following British Standards are used in the *Journal*: Chemical, Thermodynamical, and Physico-chemical quantities: B.S. 813; Engineering units: B.S. 560.

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GEORGE W. GREEN, M.B.E.

GEORGE W. GREEN, Regional Technical Officer in the Ministry of Labour, was born and educated in Manchester. He matriculated in 1910 and two years later took up his first appointment with Sir W. G. Armstrong Whitworth and Co. Ltd., at Openshaw, Manchester.

Mr. Green was at first employed in the works laboratory but in 1941 he transferred to the Research Department, where he worked under Mr. E. F. Law and Professor J. H. Andrew on problems concerned with the use of complex alloy steels for heavy armaments and high-speed tools. In 1920 he became personal assistant to the Technical Director, the late Mr. W. C. Rowden. During this period, Mr. Green contributed to the proceedings of both The Iron and Steel Institute and the Faraday Society. His next appointment, in 1923, was to the position of Assistant Manager of the Metallurgical Departments, and he took charge of the iron foundries a year later. His final appointment with Sir W. G. Armstrong Whitworth and Co., Ltd., came in 1925, when he became Manager in the department manufacturing high-speed steels and alloy steels for commercial use. In this department he was concerned with melting, forging, and heat treatments, and he specialized in the hot-rolling of complex alloy steels to very fine limits. In particular he was concerned with the research and development of the original nickel–chromium–molybdenum steels from their inception in 1922.

After the re-organization that gave rise to the English Steel Corporation, Mr. Green resigned from the Armstrong Whitworth works and took up one of the first technical posts in the Ministry of Labour. In his present capacity as an Advisor he is concerned with technical labour problems, including vocational training and industrial rehabilitation, and with problems concerning the location of metallurgical and similar heavy industries.

In 1946, Mr. Green was awarded the M.B.E. He was elected a Fellow of the Institution of Metallurgists in the following year, and became President of the Leeds Metallurgical Society in 1950. In this capacity he serves as an Honorary Member of Council of The Iron and Steel Institute. He became a Member in 1917.

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G. W. Green, M.B.E.
Honorary Member of Council

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

SPECIAL MEETING IN GLASGOW 1950

A SPECIAL MEETING OF THE IRON AND STEEL INSTITUTE was held in Glasgow from Tuesday, 12th September, to Friday, 15th September, 1950, by invitation of the West of Scotland Iron and Steel Institute. A joint session for the discussion of technical papers was held with the West of Scotland Iron and Steel Institute on Tuesday, 12th September, 1950, at the Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow. A full programme of visits to works and excursions to places of interest was arranged for Members and Ladies.

RECEPTION COMMITTEE

THE RIGHT HONOURABLE the Lord Provost of Glasgow (Victor D. Warren, Esq., M.B.E., T.D.) kindly consented to be Patron of the Meeting. A Reception Committee was formed in Glasgow, with Sir Andrew McCance, D.Sc., LL.D., F.R.S., as Chairman. Mr. W. Barr (President of the West of Scotland Iron and Steel Institute) was Chairman of the Executive Committee, and Lady McCance Chairman of the Ladies' Committee, also set up in Glasgow. Mr. P. W. Thomas, B.Sc.(Eng.), Secretary of the West of Scotland Iron and Steel Institute, was Honorary Secretary ; Mr. R. A. Hillis, M.B.E., T.D., kindly helped with many of the arrangements in Glasgow.*

The Council wish to express their thanks to the Lord Provost and Magistrates of the City of Glasgow, to the West of Scotland Iron and Steel Institute, and to the Chairmen and Members of the Reception, Executive, and Ladies' Committees, to the Scottish Iron and Steel Manufacturers, and to the Directors of the works who invited Members and Ladies to visit them or otherwise contributed to the arrangements made in Glasgow. They would also like to thank the authors of the papers, and all others who collaborated in organizing the Meeting.

TECHNICAL SESSION

The joint Technical Session with the West of Scotland Iron and Steel Institute on Tuesday, 12th September, was preceded by a short address by Mr. W. Barr, President of the West of Scotland Iron and Steel Institute, welcoming Members and Ladies and pointing out that it was twenty-three years since The Iron and Steel Institute visited Glasgow. Mr. J. R. Menzies-Wilson, O.B.E., President of the Institute, replied on behalf of the Members and Ladies and then took over the Chair.

The following papers were presented and discussed :

(1) " The Reduction of Lump Ores," by R. Wild and H. L. Saunders
(2) " The Distribution of Temperature in Ingot Moulds and Its Relation to Ingot Structure," by I. M. Mackenzie and Andrée Donald
(3) " Ingot Heat Conservation. Time Studies from Casting to Rolling," by A. V. Brancker, J. Stringer, and L. H. W. Savage
(4) " Ingot Heat Conservation : Mould and Ingot Surface Temperature Measurements," by A. V. Brancker.

A report of the discussion will be published in the October issue of the *Journal* (vol. 169).

On Wednesday, 13th September, a short film was shown on " The Continuous Casting of Steel Slabs by the Rossi-Junghans Process at the Allegheny-Ludlum Steel Corporation, Watervliet, U.S.A." The film was preceded by a short introduction by Mr. J. Savage, British Iron and Steel Research Association.

A paper on " The Production of Steel Plates in Scotland," by J. A. Kilby, was published in the September, 1950, issue of the *Journal* for the Meeting, but was not discussed.

VISITS AND EXCURSIONS

Tuesday, 12th September

In the morning, after the welcome at the Institution of Engineers and Shipbuilders in Scotland, Members took part in the technical session and Ladies visited Daly and Sons, Ltd., Sauchiehall Street, where they saw a mannequin parade.

Members and Ladies were entertained to luncheon at the Central Hotel by the Scottish Iron and Steel Manufacturers. Mr. A. Williamson, C.B.E., was in the Chair and welcomed the Members and Ladies to Glasgow ; Mr. R. Mather replied on behalf of the Institute and of the Ladies.

During the afternoon Members visited either Stewarts

* The names of those who served on these Committees were published in a Detailed Programme Book distributed to all taking part in the Meeting.

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and Lloyds, Ltd. (Clydesdale Works), or the Clyde Alloy Steel Co., Ltd., Motherwell. Ladies took part in either a motor-coach tour of Glasgow or a visit to the Scottish National Memorial to David Livingstone, at Blantyre.

In the evening Members and Ladies were the guests of the Lord Provost and Magistrates of the City of Glasgow at a Civic Reception in the City Chambers, George Square. The Lord Provost received Members and Ladies and, in an address, welcomed them to Glasgow and to the Reception. Mr. J. R. Menzies-Wilson, C.B.E., replied. Dr. C. H. Desch, F.R.S., then thanked the Lord Provost and Magistrates for their kindness in entertaining the Members and Ladies. The speeches were followed by a dance during which there were two displays of Scottish country dancing, given by members of the Scottish Country Dance Society; during the evening, also, a concert of choral singing was given by the Scottish Junior Singers, in the Council Chamber.

Wednesday, 13th September

In the morning Members had the opportunity of seeing a film on the "Continuous Casting of Steel Slabs"; they then visited one of the following works, where they were entertained to lunch:

William Beardmore and Co., Ltd., Parkhead
Lanarkshire Steel Co., Ltd., Motherwell
Babcock and Wilcox, Ltd., Renfrew
R. B. Tennent, Ltd., and Lamberton and Co., Ltd., Coatbridge.

Ladies took part in an all-day excursion by motor-coach to Loch Lomond, the Trossachs, and Stirling, with lunch and tea *en route*.

In the evening Members and Ladies were entertained by the Reception Committee to a Dinner and Dance at the Central Hotel, Glasgow; Sir Andrew McCance was in the Chair. After the Loyal Toast, Captain H. Leighton-Davies, C.B.E., proposed the Toast of the City of Glasgow. The Lord Provost replied. The Chairman then proposed the Toast of The Iron and Steel Institute; Mr. J. R. Menzies-Wilson replied.

During the dancing that followed, a display of Highland Dancing was given by a regimental team of the 1st Battalion The Highland Light Infantry (City of Glasgow Regiment), by kind permission of Lt.-Col. R. L. C. Rose, D.S.O., M.C.

Thursday, 14th September

In the morning Members visited one of the following works:

Colvilles, Ltd., Clyde Iron Works, Tollcross
Colvilles, Ltd., Clydebridge Steelworks, Cambuslang
Harland and Wolff, Ltd., Scotstoun
Duncan Stewart and Co., Ltd., Bridgeton.

Members were entertained by the Directors of Colvilles, Ltd., to luncheon at the Grosvenor Restaurant. Sir John Craig, C.B.E., D.L., who was in the Chair, expressed the pleasure of his co-directors at welcoming the Members to the works of the Company and to the luncheon. Mr. James Mitchell, C.B.E., replied.

In the afternoon Members had the opportunity of visiting one of the following three works of Colvilles, Ltd.:

Clyde Iron Works
Clydebridge Steelworks
Glengarnock.

The Ladies took part in an all-day visit by motor-coach to Edinburgh; they visited Edinburgh Castle and had luncheon at the Caledonian Hotel. On the return journey they went to South Queensferry and saw the Forth Bridge.

Members and Ladies had the evening free.

Friday, 15th September

Members and Ladies spent the whole day on board SS. *Queen Mary* II on the River Clyde. The ship left Bridge Wharf at 9.30 A.M. and proceeded to the fitting-out basin of John Brown and Co., Ltd., at Clydebank; here Members and Ladies paid a very interesting visit to the shipyards and the machine and constructional shops, including the berth where SS. *Queen Mary* and SS. *Queen Elizabeth* were built. The ship then sailed down the river Clyde, a most informative commentary being given by Mr. T. Ross Kennedy throughout the whole period of the voyage.

The route passed into the Firth of Clyde and a short distance up Loch Striven; the ship then turned a short distance up Loch Riddon, turning again to pass southward through the Kyles of Bute, south-eastward round the island of Bute, and between the Great and Little Cumbraes to Fairlie, where Members and Ladies disembarked and returned to Glasgow by train.

So ended the Meeting; everyone left with a feeling of deep regret. Not only had the fine weather on the last day enabled them to see the beautiful scenery of the Firth of Clyde at its best, but also the comprehensive programme which had been arranged, and the hospitality and kindness of the Scottish hosts, had made the whole Meeting so very interesting and enjoyable.

AUTUMN GENERAL MEETING, 1950

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 15th and 16th November, 1950, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. In the absence, owing to indisposition, of the President, Mr. J. R. MENZIES-WILSON, the chair was taken on the Wednesday and Thursday mornings by Dr. C. H. DESCH, F.R.S., Past President, and on the Wednesday afternoon by Mr. JAMES MITCHELL, C.B.E., Honorary Treasurer.

Sessions were held from 10.0 A.M. to 1.15 P.M. and from 2.30 P.M. to 4.45 P.M. on the Wednesday, and from 10 A.M. to 1.0 P.M. on the Thursday, a buffet luncheon being held in the Library of the Institute on the Wednesday.

The Minutes of the previous meeting, held in London on 26th and 27th April, 1950, were taken as read and confirmed.

The **Chairman**: We have to report with regret the deaths of two very prominent members of the Institute, Colonel Sir Charles Wright, Past President, and Sir Edward George, an Honorary Vice-President. They were

both men who had done much for the Institute, and Sir Charles Wright will be particularly remembered for what he did during his term of office as President.

The meeting stood in silence for a short time as a token of respect.

The **Chairman**: On behalf of the Institute, I have to express a welcome to our own members and to a number of visitors who are present.

AWARD OF THE SIR ROBERT HADFIELD MEDAL TO MR. WILLIAM BARR

The **Chairman**: I have much pleasure in informing you that the Council have awarded the Sir Robert Hadfield Medal, 1951, to Mr. William Barr, of Messrs. Colvilles, Ltd. (*Applause.*) The presentation will be made at the Annual General Meeting next year.

REMARKS BY THE PRESIDENT

The **Secretary** (Mr. K. Headlam-Morley): Mr. Menzies-Wilson, the President, has asked me to say that he is very sorry that he cannot attend the meeting. He is unwell. He has asked me to read to you the remarks which he would have made had he been present.

The Council have nominated Dr. C. H. Desch, F.R.S., to be an Honorary Member of the Institute. (*Applause.*) Mr. Menzies-Wilson was going to say that the list of Honorary Members is small and distinguished. It contains only six names, and Dr. Desch will add distinction to it. He has deservedly been honoured by learned societies at home and abroad, and it is fitting that we should add our tribute. Dr. Desch has been a member of the Institute for 37 years, and has served on the Council for 26 of these. He is a Past President and a Bessemer Medallist, and we all hold him in high esteem and warm affection.

You will be pleased to hear that Dr. Johan Görrissen, of Norway, has received the King's Medal for Courage in the Cause of Freedom. This was presented to him by our Ambassador in Oslo at a reception last September. (*Applause.*)

We must also congratulate Dr. Magnus Tigerschiöld, who is a Bessemer Medallist and has helped so many of our members who have visited Sweden, on receiving the Carl Lueg Medal of the German Institute, the Verein deutscher Eisenhüttenleute.

Mr. Menzies-Wilson wanted to express our indebtedness to those who helped in making the arrangements for the Special Meeting in Glasgow, and especially to Sir Andrew McCance, the Chairman of the Reception Committee, to Lady McCance and the members of the Ladies Committee over which she presided, and to Mr. Barr, the President of the West of Scotland Iron and Steel Institute and Chairman of the Executive Committee. Two important services rendered by the Institute to its members are to make it possible for them to meet people from other countries and to pay visits to works. Thanks to the hospitality of the industry in Glasgow there was plenty of opportunity for both.

The Council have accepted an invitation from the Austrian Institute, the Eisenhütte Oesterreich, to hold a Special Meeting in that country next September. An interesting programme is being prepared, and details will be announced. The headquarters will be at Graz. The dates are approximately from 5th to 15th September. The Institute of Metals are holding a meeting in Italy in the week following the meeting in Austria, and arrangements have been made by both Councils to enable members of the two Institutes to take part in both meetings.

The Symposium on High-Temperature Steels and Alloys for Gas Turbines had to be postponed, and will now be held in London on Wednesday and Thursday, 21st and 22nd February, 1951. The Special Report in which the papers will be published will be ready soon and orders can be accepted. The Fifth Hatfield Memorial Lecture had also to be postponed. It is to be hoped that Sir Frank Whittle will give that Lecture on the evening preceding the opening of the Symposium.

The Council regret that publication of the *Journal* in recent months has been delayed, and some numbers have been thinner than usual. This is due to the recent dispute in the printing industry. It is our intention that anything unavoidably omitted will be inserted in future issues.

The Annual Meeting next year will coincide with the Festival of Britain. It will be held on 30th and 31st May, and it is hoped to arrange an interesting programme of mixed papers dealing largely with blast-furnace practice in this country and in America, as well as with metallurgical subjects.

Mr. Menzies-Wilson said that his last task was a very pleasant one; it was to tell you that the Council had nominated Mr. Richard Mather to succeed him as President, if you so wish, at the Annual General Meeting next year. (*Applause.*)

CHANGES ON THE COUNCIL

The **Secretary** reported the following changes on the Council since the last General Meeting, in April, 1950:

Hon. Vice-President—Mr. E. F. Law.

Vice-President—Professor J. H. Andrew.

Members of Council—Mr. G. H. Johnson and Sir Charles Bruce-Gardner, Bt.

The following are Hon. Members of Council during their periods of office:

Mr. G. B. Thomas, President of the Cleveland Institution of Engineers, in place of Mr. E. T. Judge.

Mr. J. H. Steele, President of the Ebbw Vale Metallurgical Society, in place of Mr. R. C. Powell.

Mr. H. S. Tasker, President of The Institute of Metals, in place of Sir Arthur Smout.

Mr. G. W. Green, President of the Leeds Metallurgical Society, in place of Mr. J. Wilkinson.

Mr. A. Jackson, President of the Lincolnshire Iron and Steel Institute, in place of Mr. H. Henderson.

Mr. H. Edwards, President of the Liverpool Metallurgical Society, in place of Dr. S. J. Kennett.

Mr. K. H. Wright, President of the Staffordshire Iron and Steel Institute, in place of Dr. E. Marks.

The following are due to retire at the next Annual General Meeting and are eligible for re-election:

Vice-Presidents—Mr. G. Steel, the Hon. R. G. Lyttelton, and Captain H. Leighton Davies, C.B.E.

Members of Council—Mr. C. R. Wheeler, C.B.E., Mr. D. A. Oliver, Dr. C. Sykes, F.R.S., Mr. W. Barr, and Sir Arthur Matthews.

ANDREW CARNEGIE SCHOLARSHIP

The **Secretary**: The following Andrew Carnegie Scholarship has been awarded since the last General Meeting:

£250 to Mr. A. Rodgers (Sheffield) for an investigation of the internal friction of steels with special reference to grain-boundary phenomena.

BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATES

Messrs. J. W. Todd and W. L. Kerlie, who had been appointed scrutineers of the ballot for the election of Members and Associates, reported that the following 125 Members and 33 Associates had been elected:

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Members

Archibald, Paul A., E.Met. (Burnham, U.S.A.); **Astle,** Harry (Rotherham); **Banks,** Cecil R. (London); **Bayers,** William E., jun., B.S. (Detroit, U.S.A.); **Bhatnagar,** Parmatma Sarup, M.Sc., L.I.M. (India); **Bond,** Leslie (Rotherham); **Bowden,** James J. (Warren, U.S.A.); **Burgan,** Dean D. (Columbus, U.S.A.); **Burgess,** Harold James, B.Sc.(Eng.) (London); **Calderwood,** Young Alexander (London); **Campbell,** Kenneth P., B.A. (Houston, U.S.A.); **Chadder,** William James (London); **Chamberlain,** Alan, B.Eng. (Barrow-in-Furness); **Chambers,** David Michael (Renishaw); **Clark,** Donald S., Ph.D., M.S. (California, U.S.A.); **Clingan,** Irvine C., A.B., Ll.B. (Baltimore, U.S.A.); **Coffinberry,** Arthur S., S.B.M.S. (New Mexico, U.S.A.); **Coles,** Graham Winton, B.Sc.(Met.) (Corby); **Collins,** Archibald Lindsay (Newcastle, Australia); **Cooke,** Frederick, B.Sc. (Sheffield); **Cort,** Stewart J. (Bethlehem, U.S.A.); **Cosh,** Thomas Alexander, A.R.T.C. (Jarrow-on-Tyne); **Craig,** John Somerville, B.A. (Glasgow); **Cromwell,** D. P., Dearborn (U.S.A.); **Dakin,** Reginald Bertram (Halesowen); **Darmara,** F. N., Ph.D. (New York, U.S.A.); **Dastur,** Minu N., D.Sc. (New York, U.S.A.); **Davidson,** Roy Campbell (Melbourne, Australia); **Davis,** Ronald Walter (London); **Dean,** Stanley Keith (London); **De la Fuente De la Camara,** Juan (Reinosa, Spain); **Delwasse,** Freddy (Vireux-Molhain, France); **Dick,** Alexander Walter Henry, B.Sc. (London); **Dickenson,** John Henry Mayger (Sheffield); **Duval,** Robert (Neuilly-sur-Seine, France); **Ellison,** Raymond Mountford, B.Sc.(Hons.) (Corby); **Everett,** Norman Allen (London); **Fabry,** H. M. (Sheffield); **Fahmy,** Abel Aziz, B.Eng.(Hons.) (Sheffield); **Field,** A. J. M., B.Sc.(Tech.) (Reading); **Ford,** Colin David (London); **Fourneau,** Jean (Rodange, Luxembourg); **Frank,** Leonard, B.S. (Indiana Harbor, U.S.A.); **Girdler,** Tom Mercer (Cleveland, U.S.A.); **Glew,** John Frederick, B.Met. (Rotherham); **Goldsmith,** John M. (Missouri, U.S.A.); **Grubb,** Laurence Charles, B.Sc. (Pretoria, South Africa); **Guttenstein,** Konrad (Bournemouth); **Haffner,** Eduard K. L. (Bournemouth); **Halley,** James W. (East Chicago, U.S.A.); **Hanley,** Edward J., B.S. (Pittsburgh, U.S.A.); **Hindson,** Ralph D., B.A., A.I.M. (Ontario, Canada); **Hocking,** Henry Alfons, *Dipl. Ing.* (Zürich, Switzerland); **Holth,** Tore, M.Sc. (Lilleström, Norway); **Ilgenfritz,** Carl A. (Pittsburgh, U.S.A.); **Jacobson,** Francis S., E.Met. (Fontana, U.S.A.); **Jarleborg,** Martin Holger (Osterbybruk, Sweden); **Jenkins,** Alexander Phillips (Cardiff); **Johansen,** Frederick Charles, D.Sc. (Birmingham); **Johnson,** Hjalmar W., B.S., Ph.B. (Hammond, U.S.A.); **Lahiri,** B. N., M.Sc., Ph.D., D.I.C. (London); **Lampugnani,** Riccardo (Milan, Italy); **Landis,** Maurice N., B.S., Ph.B. (Hammond, U.S.A.); **Larrabee,** Clifford P., B.S. (Vandergrift, U.S.A.); **Legat,** Alois, *Dr. mont., Dipl. Ing.* (Leoben, Austria); **Leiper,** James Neilson (Glasgow); **Lever,** Reginald Ernest (Buenos Aires, Argentina); **Leyda,** Wallace B., B.S. (Gary, U.S.A.); **Littlewood,** Frederick Richard (London); **MacDonald,** Alexander J., jun. (New York, U.S.A.); **Markin,** Alan, North Carlton (Australia); **Marsalka,** Joseph J., M.S. (Met.Eng.) (Pittsburgh, U.S.A.); **Marshall,** John N., B.S. (Granite City, U.S.A.); **Martin,** George S. T. (Motherwell); **Meachen,** Derek, B.Sc. (Corby); **Mettam,** Arnold (Sheffield); **Mills,** William Alexander (Manchester); **Morton,** James Storrs, D.F.C., M.A., A.I.M. (Weybridge); **Newby,** Maurice Purcell, B.Sc. (London); **Oberegger,** Josef, *Dipl. Ing.* (Vienna, Austria); **O'Donnell,** Leonard, B.A. (London); **Oram,** Gavin Charles (Scunthorpe); **Park,** Alexander Gordon Paterson, A.I.M. (Vereeniging, South Africa); **Paul,** Prosanto Kumar, B.Sc., B.Met. (Belur, India); **Pienaar,** Noël Pieter, B.Sc., A.I.M. (Vereeniging, South Africa); **Reneses Hernandez,** Tomas (Reinosa, Spain); **Ruschowy,** Alfred H., *Dipl. Ing.* (Vienna, Austria); **Ryman,** Robert John (Corby); **Scheid,** Adolf J., jun. (Chicago Heights, U.S.A.); **Schuh,** Arthur Eugene, Ph.D. (Burlington, U.S.A.); **Sheppard,** Norman J. (Lithgow, Australia); **Signora,** Dr. Mario (Milan, Italy); **Simpson,** Ernest (Coventry); **Sims,** Clarence E., M.S. (Columbus, U.S.A.); **Sims,** Raymond Bernard, B.Sc. (Sheffield); **Sirvent Dargent,** Jose (Madrid, Spain); **Solomon,** John G. (Lithgow, Australia); **Standerline,** Cecil Julian (Scunthorpe); **Stewart,** Robert Graham, B.Met.Eng. (Port Melbourne, Australia); **Stobbs,** Robert William, L.I.M. (Staines); **Storm,** Fred E., B.S. (Waterburg, U.S.A.); **Sturrock,** Angus, B.S. (Chicago, U.S.A.); **Sunström,** Karl Esbjörn (Gunnebobruk, Sweden); **Swaroop,** M., F.Sc. (Aligarh, India); **Swinn,** William James (Perivale); **Tagliaferri,** Ing. Leone (Milan, Italy); **Thomas,** Vernon, L.I.M. (Cardiff); **Timmis,** L. B., M.Sc.Tech. (Fort Halstead, Kent); **Tipton,** Clyde Raymond, jun., M.S. (New Mexico, U.S.A.); **Wachtell,** Richard Lloyd, B.S. (New York, U.S.A.); **Wadsworth,** Jack (Rotherham); **Waight,** Francis Henry, B.Sc.(Eng.) (London); **Wald,** M. D., B.S. (Cleveland, U.S.A.); **Walker,** John William (Sheffield); **Wall,** Henry Charles (London); **Walters,** Stephen Joseph Michael (Manchester); **Walzel,** Frank, M.Sc., Ph.D. (Teddington); **Westermann,** J. H. (Utrecht, Holland); **Wetherly,** Donald Edmund (London); **White,** Ernest Eric (London); **Williams,** Caleb George (Birmingham); **Wilson,** John George (Workington); **Wormwell,** Frank, M.Sc., Ph.D.; **Zerbe,** William F. (Harrisburg, U.S.A.); **Yoon,** Tong-Suk (Seoul, Korea).

Associates

Abdou, A. H., B.Sc.(Eng.) (London); **Ayres,** Donald Victor (Newcastle-on-Tyne); **Beuret,** Jean (Seine, France); **Britton,** John (Swansea); **Brown,** Derek James (Newcastle-on-Tyne); **Clack,** Alan Vincett, B.A.Sc. (Sheffield); **Dutt,** Asoke Kumer, B.A. (Doncaster); **Hall,** Brian William (Birmingham); **Hinchcliffe,** Philip Russell, B.Sc.Tech. (Petersfield); **Hinett,** Oliver John (Oldbury); **Holmes,** Fred. (Newcastle-on-Tyne); **Hooper,** Frank Arthur (Birmingham); **John,** Vernon Bowen (Cardiff); **Laflin,** Reginald Ernest (London); **Lindsay,** Thomas (Glasgow); **Martin,** John W., B.A. (Cambridge); **McCabe,** William, B.Sc. (Nova Scotia, Canada); **Mason,** Henry R. (Victoria, Australia); **Miles,** George William, B.Sc.(Eng.) (Met.) (Hons.) (Rotherham); **Morrison,** James (Hollingwood); **Moss,** John Barry, L.I.M. (Hollingwood); **Noble,** Geoffrey Brian (Newcastle-on-Tyne); **Palchoudhuri,** Amitava, B.Sc. (Hons.Chem.) (London); **Perkins,** Raymond Frank (London); **Pitts,** David William Norman, B.Sc. (Hons.Met.) (London); **Singh,** Tej Bahadur, B.Sc.(Met.) (Sheffield); **Stopps,** Basil Edward Henri (Newcastle-on-Tyne); **Thomas,** Gareth (Cardiff); **Usher,** Robert (Newcastle-on-Tyne); **Vickers,** Harold (Newcastle-on-Tyne); **Williams,** Edward (London); **Wilson,** David, B.Sc.(Eng.) (Middlesbrough); **Yorke,** Joan Margaret (London).

The **Chairman** declared the candidates duly elected, and announced that the total membership of the Institute was now 4,894.

PRESENTATION OF PAPERS

The following papers were presented and discussed:

Wednesday, 15th November, 1950

Morning Session

"The Thermodynamic Background of Iron and Steel Making Processes." "Part II—Deoxidation," by F. D. Richardson, and

"Studies in the Deoxidation of Iron. Deoxidation by Aluminium," by H. A. Sloman and E. L. Evans. (*Joint Discussion*).

"Thermodynamic Aspects of the Movement of Sulphur between Gas and Slag in the Basic Open-Hearth Process," by F. D. Richardson and G. Withers.

Afternoon Session

"The Effect of Cold-Work on Steel," by J. H. Andrew, H. Lee, P. L. Chang, B. Fang, and R. Guenot.

Thursday, 16th November

"Atlas of Isothermal Transformation Diagrams of B.S. En Steels" (Special Report No. 40, 1949)

"The Transformations Alpha-to-Gamma and Gamma-to-Alpha in Iron-Rich Binary Iron–Nickel Alloys," by N. P. Allen and C. C. Early.

"The Acceleration of the Rate of Isothermal Transformation of Austenite," by M. D. Jepson and F. C. Thompson.

"The Breakdown of Austenite below the M_s Temperature," by F. C. Thompson and M. D. Jepson. (*Joint Discussion*).

A report of the discussion on these papers will be published in the October issue of the *Journal* (vol. 169).

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Physical and Mechanical Properties of Segregates in Two Alloy Steels

By H. M. Finniston, B.Sc., Ph.D., and T. D. Fearnehough, Assoc. Met.

SYNOPSIS

The paper describes techniques for the measurement of hardness variation and tensile and impact properties of segregates isolated from two alloy-steel forgings. The quantitative differences in properties between the segregates and the matrices surrounding them after various heat-treatments are detailed and the former are shown to be significantly harder, and to have a higher proof and maximum stress and lower elongation and impact values on all casts. The differences in chemical composition between segregate and matrix are also reported quantitatively.

Photomicrographs are shown of the structures of segregate and matrix, and attention is drawn particularly to the variations in structure and concentration of non-metallic inclusions within the segregate. The influence of the inclusions on the mechanical properties of the segregate is discussed.

Photomacrographs are given, which indicate the mode of formation of segregates.

Introduction

THE use of large alloy-steel forgings for important naval armaments led the Bragg Laboratory (Naval Ordnance Inspection Department), Sheffield, to investigate the metallurgical nature and characteristics of the segregates in such forgings. Until 1944, the main research effort was devoted to the development and application of a spectrographic technique for the micro-analysis of individual segregates.[1, 2] In late 1943, the experimental work was extended to cover the physical and mechanical properties of segregates.

This work was confined to segregates in a 3·5% nickel steel and a 2·5% nickel–vanadium steel, with the following composition :

Element, %	3·5% Ni Steel	2·5% Ni-V Steel
C	0·37	0·41
Si	0·24	0·19
Mn	0·70	0·74
P	0·035	0·021
S	0·034	0·031
Ni	3·61	2·46
Cr	0·17	0·13
Mo	0·10	0·10
V	...	0·11

Both steels were made in the acid open-hearth furnace and were top-poured into wide-end-up moulds. The nickel-steel ingot weighed 20 tons and the nickel–vanadium steel ingot 37 tons. After a forging reduction of approx. 2 : 1 in both cases, a full transverse section from the top discard from each forging was obtained from the manufacturer.

Location of the Segregates for Test

From each large section, a 1⅛-in. thick slice was parted transversely to the forging (or ingot) axis, enabling a convenient test-piece length to be prepared from segregates that were substantially continuous and straight. The transverse faces of each slice were machined parallel, finely ground, sulphur printed, and macro-etched with Humfrey's reagent.[3] Figures 3*a* and 4*a* are reproductions of part of the complete sulphur prints of one of the transverse faces of the 3·5% nickel and 2·5% nickel–vanadium steel slices respectively ; Figures 3*b* and 4*b* are the corresponding macrostructural patterns.

Comparison of Figs. 3*a* and *b* and Figs. 4*a* and *b* shows that the segregates revealed on sulphur printing can be matched with those on the photomacrograph of the same surface, although the detail brought out on macro-etch is greater. Figures 3 and 4 show the irregular shapes and variations in size of segregates. (Segregates also vary in their shape and dimensions in longitudinal section.) In the sections examined

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Dr. Finniston, formerly of the Bragg Laboratory (N.O.I.D.), Sheffield, is now Head of the Metallurgy Division of the Atomic Energy Research Establishment, Harwell. Mr. Fearnehough is on the staff of the Bragg Laboratory (N.O.I.D.).

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the incidence of the larger segregates tends to be greater towards the centre of the ingot or forging.

In general, the photomacrographs (and sulphur prints) of the opposite parallel transverse surfaces of a slice show an identical pattern of the larger segregates. By marking the ends of individual segregates on these opposite transverse surfaces, segregates running the full thickness of a slice could be isolated for mechanical testing.

Segregates from both alloy steels were tested for :

(1) Hardness
(2) Tensile properties
(3) Notch impact properties (Izod)
(4) Composition (by spectrographic and microchemical tests)
(5) Macro- and microstructure.

HARDNESS TESTS

Standardization of Procedure

Tests were made on a standard Vickers machine using a 1-kg. load. Calibration of this instrument with standard blocks covering a wide range of hardness showed the reproducibility of tests to be of the same order as with a 30-kg. load.

From the nickel and nickel–vanadium steel slices, sulphur printed and macro-etched as previously described, blocks 2 in. × 2 in. × $1\frac{1}{8}$ in. were cut from various positions in the segregated zones. These blocks were either oil- or water-quenched from 850° C. and the transverse end faces were reground. One transverse face (the test face) was then polished and etched in Oberhoffer's reagent[3] for 40 sec. to re-develop the macrostructure sufficiently to locate the segregates. A series of hardness tests, run on standard blocks prepared as for the segregate tests, confirmed that light etching with Oberhoffer's reagent did not significantly affect the hardness determined with the 1-kg. load.

A hardness traverse was made across a large number of the segregates on each block, at intervals of approx. 0·01 in. Each hardened block was tempered at 300°, 400°, 500°, and 600° C. in successive treatments, the test face being prepared for hardness exploration between each treatment as described for the block in the hardened condition. The same segregates were re-traversed for hardness after each tempering treatment. Preparation of the test samples after each tempering removed 0·005–0·01 in. from the test face, but this did not materially alter the shape or dimensions of the segregates examined.

Figure 5*a* shows the hardness variation across a typical segregate in the 3·5% nickel steel in the oil-hardened and tempered condition, and Fig. 6*a* the results of corresponding tests on another segregate of the same steel when water-quenched and tempered. The results of hardness tests on an oil-quenched and tempered segregate in the 2·5% nickel–vanadium steel are given in Fig. 7*a* ; Fig. 8*a* gives results for a water-hardened and tempered segregate. The photographic strips, Figs. 5*c*–8*c*, are enlargements of the particular segregates (the large black areas) examined by reflected light.

Hardness Characteristics of Segregates

The segregates are generally harder than the adjacent matrix, a difference in hardness persisting even in the most fully tempered specimens (*cf.* Figs. 5*a*–8*a* and Figs. 5*c*–8*c*). With very few exceptions, the hardness traverses of similarly heat-treated segregates in a particular steel cover almost the same hardness range, although the detail of the traverses varied with the form of the segregate. To obtain the maximum hardness difference between segregate and matrix, a hardness traverse must be made across the full width of a segregate. Failure to do this accounted for the comparative flatness of the hardness curve in certain cases. There is evidence that with segregates smaller than those shown in Figs. 5*a*–8*a*, the maximum hardness difference between segregate and matrix is less pronounced.

Water-quenching and tempering, as compared with oil-quenching and tempering of the same steel, raises the hardness level of both segregate and matrix by approximately similar amounts. The general features of segregates whether heat-treated by water-hardening or oil-hardening are, however, essentially similar. The average hardness of segregates and matrices, tempered at various temperatures, was estimated from the traverses, and the results are included in Tables I and II.

TENSILE TESTS

Standardization of Procedure

For the micro-tensile tests, the Houndsfield Tensometer[4] was employed. The size of test piece was determined by the cross-sectional area of the largest

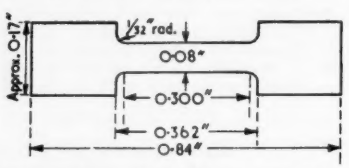

Fig. 1—Dimensions of miniature tensile test piece

segregates available (about 0·10 in. dia.). The details of the test piece finally adopted are shown in Fig. 1. Reproducibility tests and comparative tests against the standard B.S. test piece (0·564 in. dia.) were carried out on bars of four different steels with the following analyses :

Steel	C, %	Si, %	Mn, %	P, %	S, %	Ni, %	Cr, %	Mo, %
1	0·40	0·21	0·79	0·033	0·035	1·0	...	...
2	0·32	0·20	0·55	0·032	0·043	3·26	0·62	0·23
3	0·40	0·39	0·71	0·010	0·009	1·69	1·22	0·32
4	0·22	0·24	0·53	0·013	0·01	0·23	3·28	0·58

These were heat-treated to several hardness levels covering the range of hardness of the segregates determined above.

Statistical analysis of the results of these tensile tests showed that the error variances in proof stress, maximum stress, and elongation for the B.S. test pieces and for the tensometer tests did not differ significantly, although the tensometer error variance was the larger.

The 16 sets of replicate tensometer tests covered the tensile range 45–90 tons/sq. in., and the standard deviation was 0·3 ton/sq. in. in proof stress, 0·5 ton/sq. in. in tensile strength, and 1·0% in elongation. The reproducibility of duplicate tests on B.S. test pieces was closer. The proof stress of the full-size test piece was almost invariably higher than the

corresponding value on tensometer test, the difference amounting to 1·8 tons/sq. in. with a standard deviation of 1·6 tons/sq. in. Both the maximum stress and elongation of the full-size test piece were consistently lower by 0·8 ton/sq. in. (standard deviation 0·75 ton/sq. in.) and 1·5% (standard deviation 0·8%) respectively.

Tensile Properties of Segregates

Blocks containing segregates of suitable diameter were heat-treated by oil-hardening from 850° C. and were tempered at various temperatures from 300° to 600° C. The ends of the individual segregates for test were located on opposite faces of the block after grinding and etching with Oberhoffer's reagent. The centre of the segregate ends was punch-marked and the segregate was then sawn out and turned to test-piece dimensions. A similar procedure was adopted in preparing test pieces from the matrix adjacent to the segregate. The results of tensile tests on six segregates and adjacent matrices from blocks of the two alloy steels in several conditions are tabulated in Tables I and II, together with the maximum-stress/average-hardness ratio.

From a statistical analysis of these results, the following general conclusions can be drawn :

(i) Segregates and matrices similarly heat-treated show a greater variance in tensile properties than was found in the standardization tests

(ii) With the exception of a few special cases, referred to below, the proof stress and maximum stress of segregates are significantly greater than the corresponding values for tests from the matrices. In certain segregates, particularly those of high tensile strength, fracture stress occurs near proof stress (*see* Table I). Such premature failure can be associated with the incidence of non-metallic inclusions at the surface of the journal of the test piece, as described on p. 11.

Table I

TENSILE TESTS ON SEGREGATES AND MATRICES OF 3·5% Ni STEEL

(Oil-hardened at 850° C.)

Tempering Temp., °C.	Segregate				Matrix			
	0·3% Proof Stress, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	0·3% Proof Stress/Max. Stress	0·3% Proof Stress, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	0·3% Proof Stress/Max. Stress
600	54·3	64·5	16·4	0·84	47·9	59·0	21·7	0·81
	51·0	57·5	12·4	0·89	47·5	60·0	22·3	0·79
	55·0	64·5	14·7	0·85	52·5	61·0	21·1	0·86
	52·0	62·0	23·0	0·84	50·0	60·0	22·6	0·83
	53·1	61·5	20·0	0·86	51·0	60·0	20·4	0·85
	53·1	64·0	18·0	0·83	52·0	62·0	21·5	0·84
Mean	53·1	62·3	17·4	0·85	50·2	60·3	21·6	0·83
Mean hardness*		286				260		
Max. stress/hardness		0·22				0·23		
500	65·3	72·0	16·6	0·91	62·5	69·0	16·0	0·91
	65·0	72·0	12·5	0·90	63·0	70·0	17·8	0·90
	66·3	73·0	14·5	0·91	63·8	70·0	17·4	0·91
	65·0	71·0	13·3	0·92	62·5	69·0	14·1	0·91
	64·0	70·0	14·5	0·91	63·0	70·0	18·2	0·90
	66·5	72·0	9·3	0·92	64·0	69·0	18·1	0·93
Mean	65·4	71·7	13·4	0·91	63·1	69·5	16·9	0·91
Mean hardness*		340				309		
Max. stress/hardness		0·21				0·22		
400	78·1	80·0	12·6	0·98	72·5	77·8	15·3	0·93
	74·3	81·0	2·8	0·92	72·5	78·0	13·3	0·93
	75·4	80·5	5·3	0·94	72·0	78·0	15·2	0·92
	77·5	80·0	3·3	0·97	72·5	78·0	14·1	0·93
	75·0	80·0	10·5	0·94	75·0	77·0	14·5	0·97
	77·5	81·5	10·7	0·95	71·0	88·0	14·6	0·81
Mean	76·3	80·5	7·5	0·95	72·6	79·5	14·5	0·92
Mean hardness*		392				359		
Max. stress/hardness		0·21				0·22		
300	85·0	97·5	6·3	0·87	85·0	92·5	13·7	0·92
	87·5	96·5	2·9	0·91	85·0	90·0	11·9	0·94
	†	87·0	2·6	...	85·0	90·0	12·4	0·94
	†	86·0	2·3	...	85·5	90·5	11·1	0·94
	†	75·0	1·3	...	85·5	91·0	13·3	0·94
	87·0	94·5	11·2	0·92	80·0	90·5	12·3	0·88
Mean	86·5	89·4	4·4	0·90	84·3	90·8	12·4	0·93
Mean hardness*		447				401		
Max. stress/hardness		0·20				0·23		

* Estimated from hardness traverses † Fracture stress occurred before proof stress was measured

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(iii) The yield-point/maximum-stress ratios for similarly treated segregates and matrices are not significantly different

(iv) The elongation of segregates is significantly lower than that of the corresponding matrices. It shows considerable variation in any one series of tests, and particularly in tests on samples of higher tensile strength

(v) The maximum-stress/hardness ratio is affected by the composition of the steel, but is independent of the hardness of the material. This ratio is generally slightly higher for the matrix than for the segregate.

NOTCHED IMPACT TESTS

Standardization of Procedure

The apparatus for the notch impact testing of miniature test pieces follows the construction of the standard 120-ft.lb. Izod impact machine. The hammer consists of a hardened steel blade rigidly fixed between two steel discs. The weight of the moving parts is 3 lb. and the height of fall of the centre of gravity of the hammer is 2 ft. The specimen is held in a vice fixed in the base of the machine. The dial on which the 'equivalent Izod' impact value is read is fixed

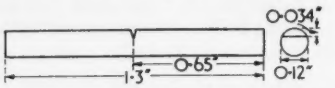


Fig. 2—Details of miniature impact test piece

on the side of the instrument and a pin attached to the swinging arm engages the pointer on the dial, as in the standard machine.

The test piece finally adopted, and shown in Fig. 2, is based on the round notched B.S. test pieces. The shape and dimensions of the test piece were governed partly by machining conditions and partly by the maximum size of the segregates. Notches were ground

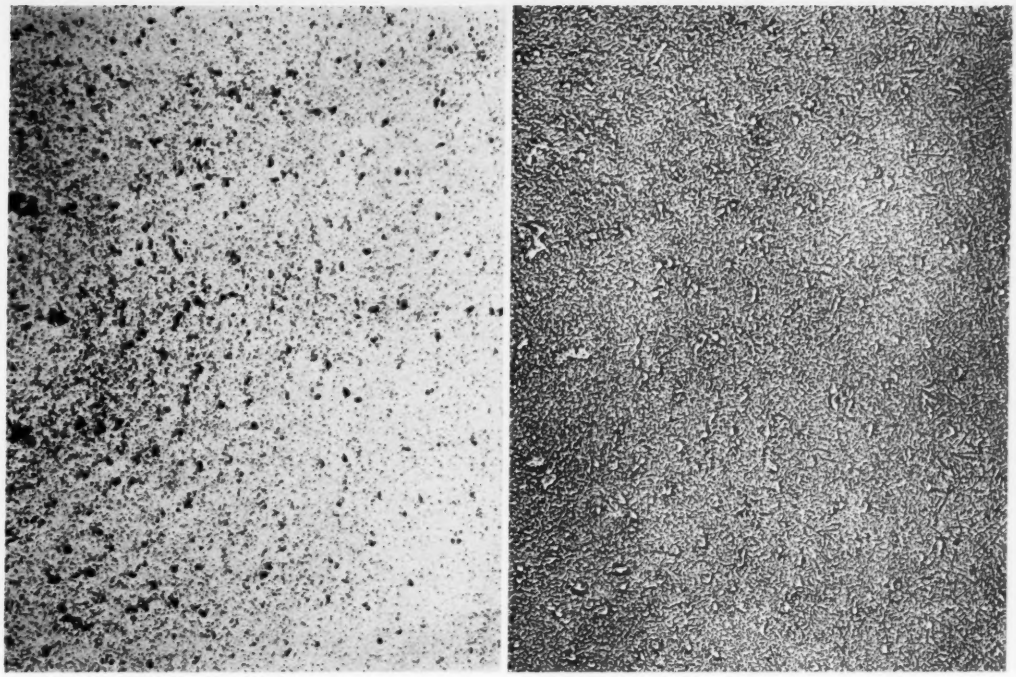
Table II

TENSILE TESTS ON SEGREGATES AND MATRICES OF 2·5% Ni–V STEEL

(Oil-hardened at 850° C.)

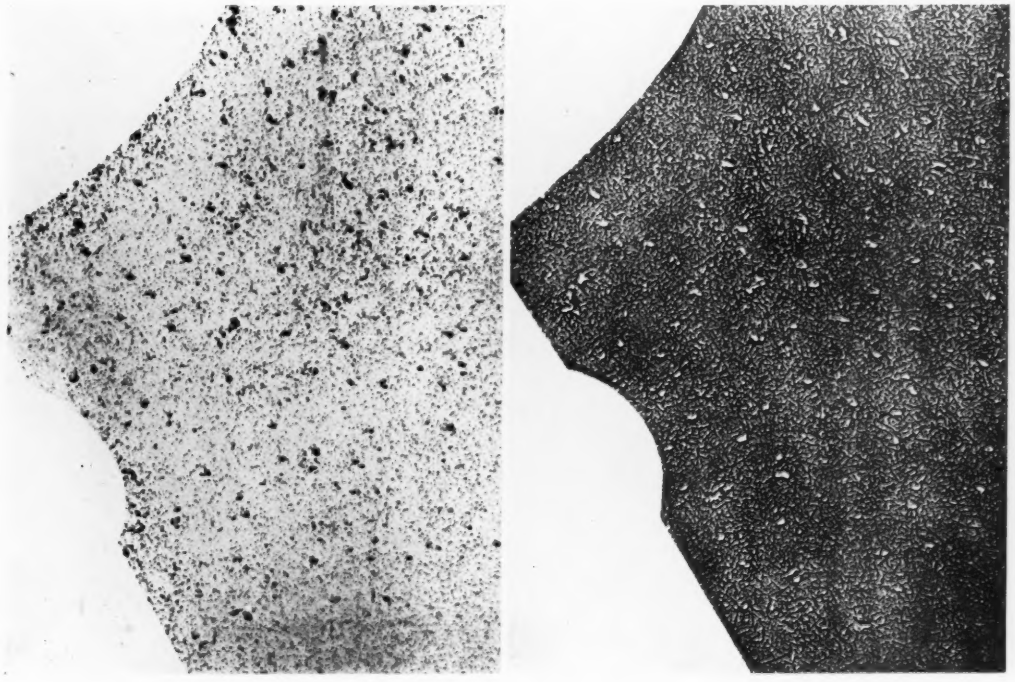
Tempering Temp., °C.	Segregate				Matrix			
	0·3% Proof Stress, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	0·3% Proof Stress/Max. Stress	0·3% Proof Stress, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	0·3% Proof Stress/Max. Stress
600	53·4	62·0	15·6	0·86	52·5	60·0	18·3	0·88
	57·0	64·0	19·7	0·89	52·6	60·0	20·3	0·88
	55·5	63·0	11·6	0·88	52·5	60·0	23·1	0·88
	55·3	62·0	20·7	0·89	52·0	59·5	22·2	0·87
	53·0	60·5	19·4	0·88	51·3	59·5	23·7	0·86
	53·4	62·0	13·0	0·86	52·5	59·5	20·9	0·88
Mean	54·6	62·2	16·7	0·88	52·2	59·8	21·4	0·88
Mean hardness*		330				310		
Max. stress/hardness		0·19				0·19		
500	65·7	75·5	9·3	0·87	60·0	69·5	17·2	0·86
	69·0	75·0	6·5	0·92	63·0	70·0	18·1	0·90
	65·0	72·0	8·4	0·90	62·5	69·0	16·3	0·91
	65·0	72·0	11·4	0·90	62·0	67·5	21·6	0·92
	66·8	73·0	9·5	0·92	64·0	69·0	22·6	0·93
	65·4	73·4	12·6	0·89	64·0	70·0	16·4	0·91
Mean	66·2	73·5	9·6	0·90	62·6	69·1	18·7	0·91
Mean hardness*		359				329		
Max. stress/hardness		0·20				0·21		
400	70·0	75·0	7·8	0·93	72·0	77·5	14·8	0·93
	72·8	79·0	3·0	0·92	70·5	77·5	13·3	0·91
	70·0	76·0	16·5	0·92	70·0	77·5	12·2	0·90
	70·0	77·5	7·5	0·90	69·0	75·0	16·5	0·92
	70·0	75·5	9·8	0·93	70·0	77·5	14·9	0·90
	70·0	77·5	15·7	0·90	68·0	75·0	16·1	0·91
Mean	70·5	76·8	10·0	0·92	69·9	76·7	14·6	0·91
Mean hardness*		417				394		
Max. stress/hardness		0·18				0·19		
300	...	92·5	2·3	...	86·2	95·0	11·5	0·91
	90·0	98·0	3·3	0·92	86·5	95·0	14·2	0·91
	90·8	102·0	9·9	0·89	85·0	91·0	11·4	0·93
	90·0	102·0	11·5	0·88	87·5	95·0	13·1	0·92
	90·0	98·0	4·3	0·92	87·5	97·5	13·0	0·90
	87·5	98·0	3·9	0·89	85·0	95·0	11·8	0·89
Mean	89·7	98·4	5·9	0·90	86·3	94·8	12·5	0·91
Mean hardness*		499				451		
Max. stress/hardness		0·20				0·21		

* Estimated from hardness traverses



(a) (b)

Fig. 3—Transverse face of 3·5% Ni steel slice : (*a*) Portion of sulphur print ; (*b*) corresponding macrostructure



(a) (b)

Fig. 4—Transverse face of 2·5% Ni-V steel slice : (*a*) Portion of sulphur print ; (*b*) corresponding macrostructure

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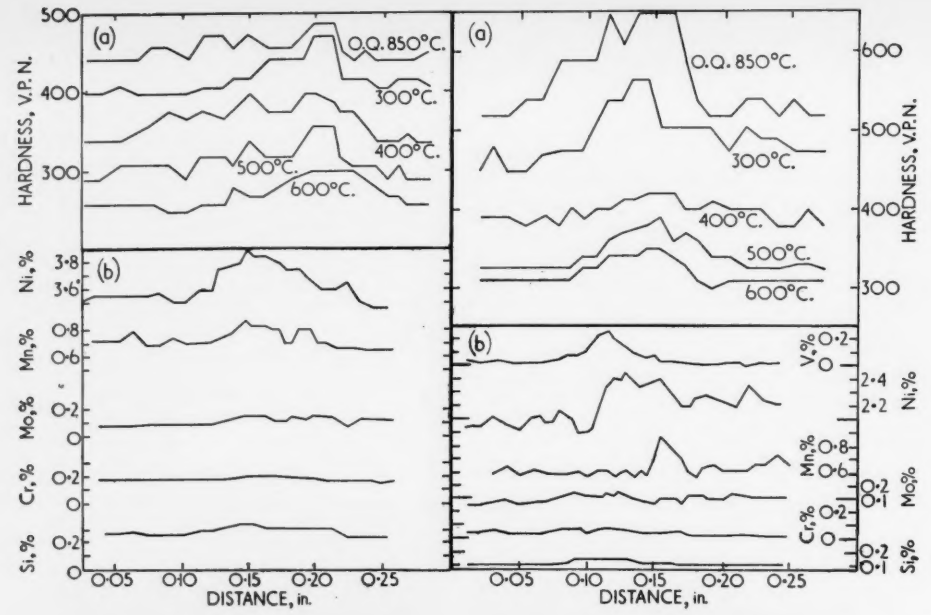
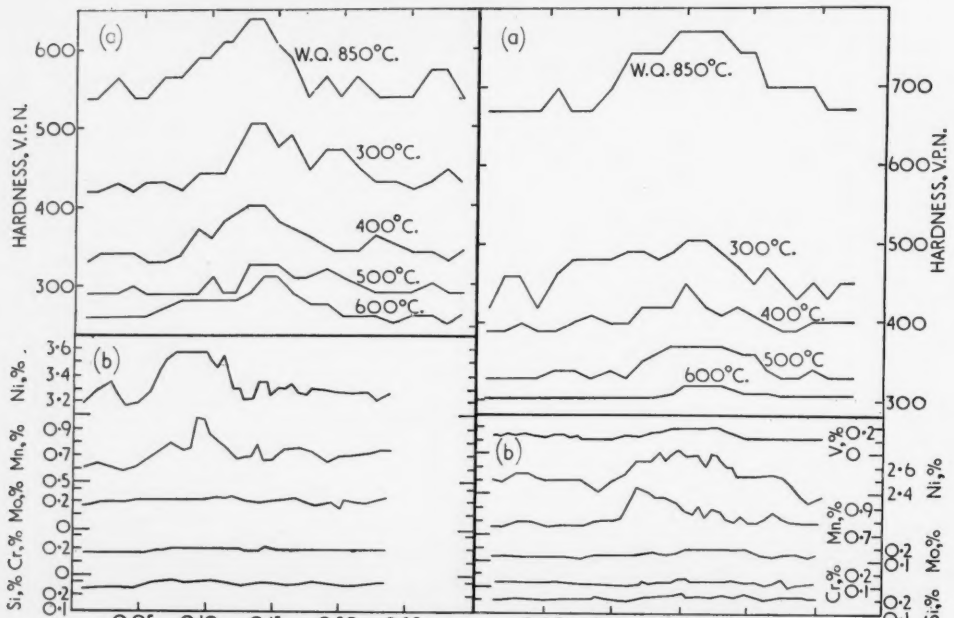


(c) Oil-quenched

(c) Oil-quenched



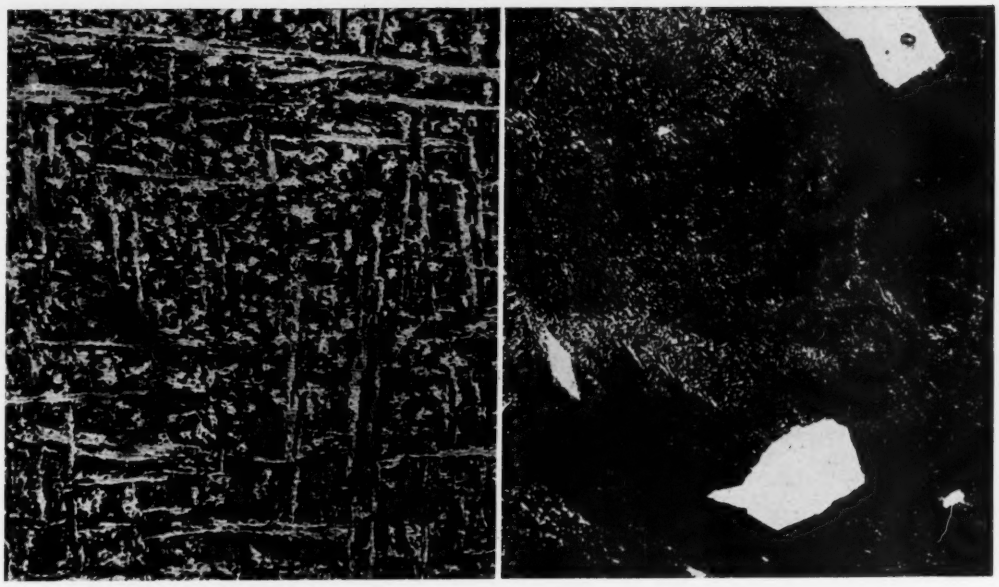
(c) Water-quenched

(c) Water-quenched

Figs. 5 and 6—Typical segregates in 3·5% Ni steel, tempered at various temperatures: (*a*) Hardness variation across segregate ; (*b*) spectrographic traverse showing variation in composition ; (*c*) enlargement of segregate examined by reflected light

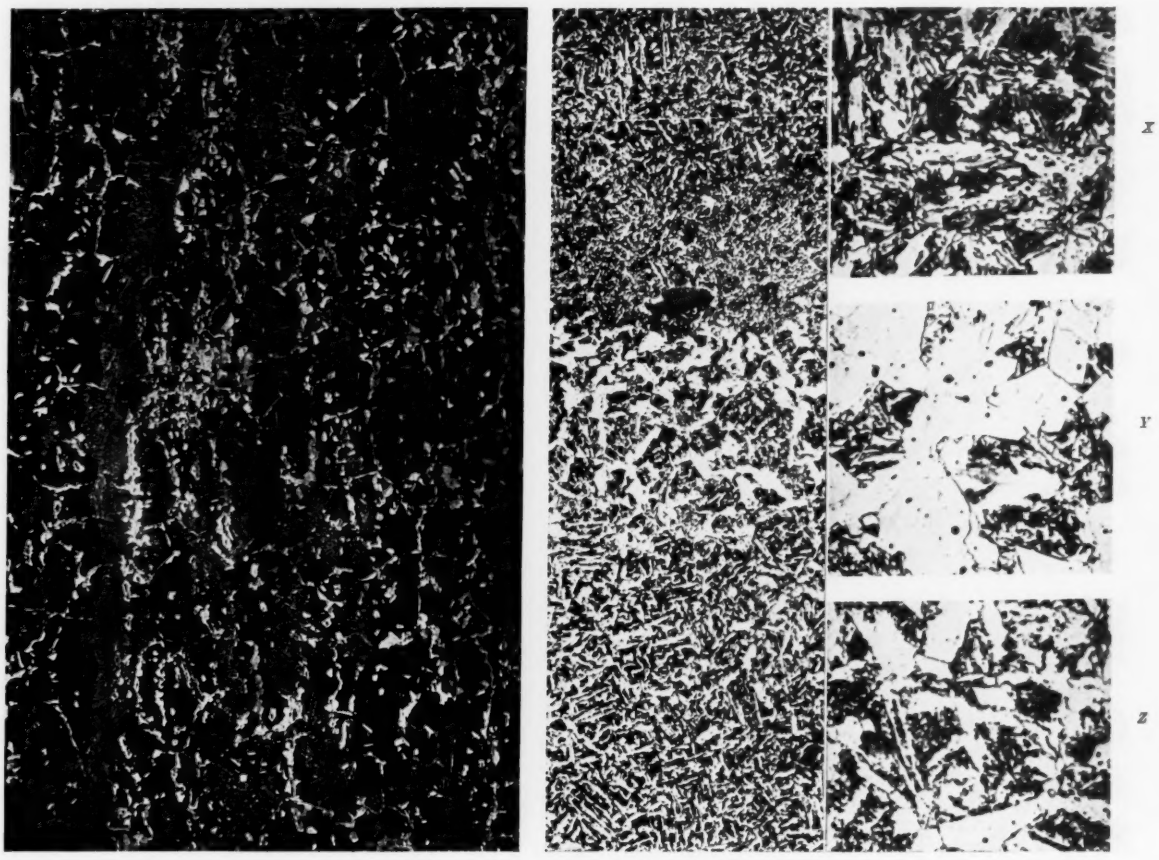
Figs. 7 and 8—Typical segregates in 2·5% Ni steel, tempered at various temperatures : (*a*) Hardness variation across segregate ; (*b*) spectrographic traverse showing variation in composition ; (*c*) enlargement of segregate examined by reflected light

Finniston and Fearnehough]



Segregate Matrix

Fig. 9—Microstructure of transverse section through segregate and adjacent matrix in 3·5% Ni steel, as-forged × 300



(a) (b) (c)

Fig. 10—Microstructure of segregate and adjacent matrix in 3·5% Ni steel : (*a*) Longitudinal section, as-forged × 20 ; (*b*) transverse section, annealed × 75 ; (*c*) microstructure at *X*, *Y*, and *Z* × 500

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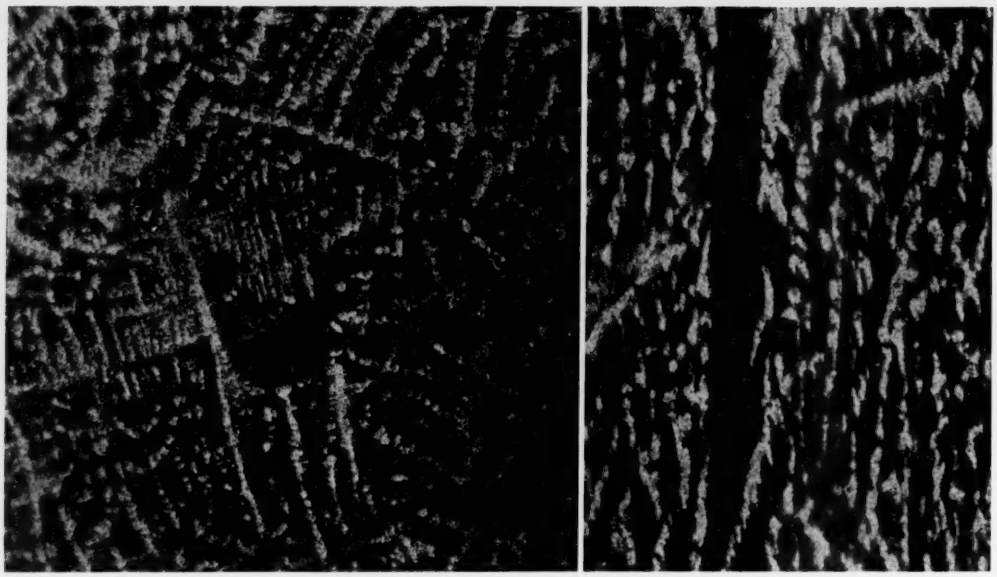

(a) (b)

Fig. 11—Macrostructure of sections through a typical segregate: (*a*) Transverse section; (*b*) longitudinal section × 8

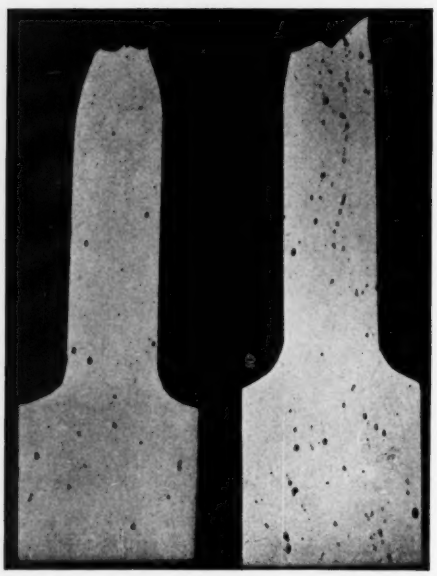

Fig. 12—Longitudinal section through tensile test pieces showing inclusion concentration in segregate: (*a*) Segregate test piece; (*b*) matrix test piece

in the test piece and were checked for accuracy by screening before breaking.

The miniature Izod impact machine was calibrated against the 120-ft.lb. standard impact tester, using standard B.S. impact test pieces (3 notches) and miniature test pieces (2 notches) prepared from the four steels used in the tensometer test standardization. A correlation coefficient of 0·982 was obtained for the results from the two machines. The average scatter of impact values on a 3-notch standard Izod test was 4 ft.lb. with a standard deviation of 3·5 ft.lb. for the 16 sets of tests. For the miniature test pieces, results were reproducible to within less than 0·1 ft.lb. with a standard deviation of the same order.

Notched Impact Properties of Segregates

The sample segregates and matrices for impact testing were isolated from heat-treated blocks as

Table III

LONGITUDINAL IMPACT TESTS ON SEGREGATES AND MATRICES OF TWO ALLOY STEELS

(Oil-hardened at 850° C.)

Steel	Tempering Temperature, °C.	Observed Impact Value on 6-ft.lb. Machine, ft.lb.		Calculated Impact Value for 120-ft.lb. Machine, ft.lb.		Observed Impact Value of B.S. Test Pieces on 120-ft.lb. Machine, ft.lb.
		Segregate	Matrix	Segregate	Matrix	
3·5% Ni Steel	600	2·15	2·50	53	59	
		2·00	2·40	49	57	
		2·15	2·40	53	57	48; 50
		2·00	2·50	49	59	
		1·90	2·35	48	55	
			Mean	50	57	49
	500	1·70	1·85	43	46	
		1·70	1·70	43	43	
		1·70	1·90	43	48	42; 43
		1·50	1·90	39	48	
		1·40	2·15	37	52	
			Mean	41	47	43
	400	0·30	0·40	7	10	
		0·15	0·30	3	7	4; 8·5
		0·20	0·30	5	7	
			Mean	5	8	6
	300	0·15	0·35	3	8	
		0·15	0·35	3	8	3·5; 4
		0·10	0·40	2	10	
			Mean	3	9	4
2·5% Ni–V Steel	600	2·35	2·50	55	60	
		2·20	2·65	54	63	
		2·15	2·70	57	64	
		2·20	2·70	58	64	
		2·35	2·75	60	65	
			Mean	57	63	
	500	1·55	1·90	39	47	
		1·60	1·85	41	44	
		1·70	1·85	42	44	
		1·60	1·80	41	45	
			Mean	41	45	
	400	2·00	1·70	49	43	
		0·70	1·60	24	41	
		1·90	1·60	47	41	
		0·60	1·20	22	33	
			Mean	36	40	
	300	0·60	0·70	22	24	
		0·30	0·80	...	26	
		0·30	0·80	...	26	
			Mean	22	25	

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described on p. 6. The blocks from both types of steel were oil-quenched from 850° C. and tempered at temperatures of 300°, 400°, 500°, and 600° C., and three to five segregates were taken from each tempered block. The miniature impact test pieces were broken in the 6-ft.lb. machine ; the results are detailed in Table III.

The conclusions to be drawn from these tests are as follows :

(i) The variations in impact value of the matrices from the two alloy steels and of segregates from the nickel steel are not significant. The results of tests on segregates from the nickel–vanadium steel show considerably greater variance, because of particularly low impact values

(ii) The impact value of segregates is significantly lower than the corresponding value for adjacent matrices.

An explanation of the erratic variation in the impact value of segregates is offered later.

In a further series of miniature impact tests, the test pieces were prepared with the main axis transverse to the ingot axis. The segregate was located at the centre of the test length and the notch was cut at its centre. The results of these transverse impact tests are given in Table IV.

The results confirm the general conclusions drawn from the longitudinal miniature tests and in particular confirm the lower values of the segregation tests.

Longitudinal B.S. impact test pieces of the 3·5% nickel steel in several treated conditions were prepared from the segregated zone. The results reported in the last column of Table III agree reasonably well with the corresponding values obtained on miniature test pieces prepared from segregates and matrices.

SPECTROGRAPHIC AND CHEMICAL TESTS

Micro-analytical Techniques

The early stages of research on segregation in steel ingots were confined mainly to a determination of the differences in composition between segregates and their adjacent matrices.[5, 6] Relatively large amounts of material are required for chemical analyses, which are only average indications of the composition of the portion of steel included in the drillings used.

A spectrographic technique for micro-analysis of steels has been developed by Barker, Convey, and Oldfield.[1] The method is capable of giving the amount of each metallic element in the steel on a sample of

Table IV

TRANSVERSE IMPACT TESTS ON SEGREGATES AND MATRICES FROM 3·5% NICKEL STEEL

(Oil-hardened at 850° C.)

Tempering Temp., °C.	Segregate	Matrix
300	0; 0; 0; <4; 0; 0; 0; <4; 0; 0	<4; <4; <4; <4; <4; <4; <4; <4
400	<4; 0; <4; 0; 0; 0; <4; <4; 0; 0	8; 7; 7; 7; 7; 6; 7; 7; 8
500	<4; <4; 8; <4; <4; 8; 6; 6; <4; 6	16; 12; 12; 16; 12; 14; 12; 12; 12; 14
600	<4; 6; 6; 12; 10; 12; 6; 6; <4; <4	12; 12; 14; 12; 14; 12; 12; 14; 12; 14

5×10^{-6} g., corresponding to a zone of 0·3 mm. dia. and 0·018 mm. deep. A continuous record of the analytical changes can be obtained, and the difference in composition is thereby measured at 0·1-mm. intervals. At the time of this investigation the method was not applicable to the determination of carbon, phosphorus, and sulphur.

The metalloids were determined by micro-chemical methods using the Spekker absorptiometric technique developed by Vaughan.[7] The sample was obtained by drilling through the segregate (of about 0·10 in. dia.) or matrix with a $\frac{1}{16}$-in. drill.

Spectrographic and Chemical Tests on Segregates

All the segregates explored for hardness variations were tested spectrographically and chemically by the above micro-methods. Figures 5*b* and 6*b* show the results of typical spectrographic traverses of the nickel-steel segregates shown in Figs. 5*c* and 6*c* respectively. Figures 7*b* and 8*b* refer to the nickel–vanadium steel segregates of Figs. 7*c* and 8*c* respectively.

The spectrographic tests showed a variation in composition across the segregate. The maximum increases in the alloying elements occurred in the segregate, although minor variations in composition showed up in the darker etching areas corresponding

Table V

AVERAGE COMPOSITION OF SEGREGATES AND ADJACENT MATRICES BY SPECTROGRAPHIC TRAVERSE

Element	3·5% Nickel Steel						2·5% Nickel–Vanadium Steel					
	No. 1		No. 4		No. 6		No. 1		No. 3		No. 6	
	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix
Si	0·30	0·16	0·28	0·26	0·29	0·28	0·24	0·22	0·23	0·22	0·22	0·23
Mn	0·79	0·73	0·76	0·72	0·74	0·68	0·87	0·77	0·88	0·77	0·90	0·78
Ni	3·77	3·55	3·51	3·25	3·70	3·35	2·69	2·50	2·69	2·55	2·83	2·63
Cr	0·18	0·16	0·18	0·17	0·18	0·18	0·16	0·13	0·13	0·13	0·14	0·13
Mo	0·13	0·08	0·22	0·18	0·20	0·20	0·15	0·13	0·15	0·14	0·15	0·14
V	...	...	...	...	...	...	0·22	0·12	0·19	0·13	0·14	0·13

to the interdendritic material in the matrix. Manganese, nickel, molybdenum, and vanadium have the greatest tendency to segregate, but their maxima do not occur at the same position in the traverse. There is no spectrographic evidence of any marked variations in composition immediately adjacent to inclusions, which might result from reaction between the inclusion and its surrounding metal envelope.

The average analysis of three segregates and their adjacent matrices in the nickel and nickel–vanadium steels calculated from the appropriate spectrographic traverses are given in Table V. The results of microchemical analysis of other segregates and their adjacent matrices from both steels are given in Table VI. The results confirm closely the spectrographically determined content of the alloying metals detailed in Table V. In regard to carbon, sulphur, and phosphorus, the greatest variation between segregate and matrix occurs with the two latter elements, particularly in segregate 7 of the 3·5% nickel steel and segregates 7 and 8 of the 2·5% nickel–vanadium steel.

The micro-analyses of the segregates are shown to be of the same order as the macro-chemical analysis given on p. 5.

MICROSTRUCTURAL EXAMINATION OF SEGREGATES

The microstructural condition of segregates and adjacent matrices from both classes of steels has been investigated in samples taken from the as-forged blocks after annealing and after hardening and tempering. The differences between segregate and matrix in the hardened and hardened and tempered conditions were small, and this section is confined to a description of samples in the as-forged or fully annealed condition.

A transverse section of the 3·5% nickel steel in the as-forged condition showed that in the matrix the ferrite occurs primarily as an intergranular constituent or in isolated masses, whereas, in the segregate, precipitation is along cleavage planes and in the form of small particles within the grain. The eutectoid in both segregate and matrix is finely sorbitic with a tendency to be faintly lamellar in the case of the matrix. Figure 9 shows typical areas of the segregate and matrix respectively at high magnification.

A longitudinal section (Fig. 10*a*) through one of the segregates from the as-forged block shows essentially the characteristics of the transverse section of Fig. 9. The comparative straightness of the segregate (and this applies to the lengths of segregate at both ends, not reproduced in the photograph) and branches, which are similar in structure to the main segregate, are evident. The branches correspond to interdendritic arms running from the main segregate. There is an intermittent band of ferrite nodules, the majority of which have a non-metallic inclusion, running down the centre of the segregate. (Viewed with a hand lens (× 10) Fig. 10*a* shows the non-metallic inclusions as dark spots in the centre of the ferrite nodules.)

The structure of the annealed segregates of the nickel steel are shown in the transverse section reproduced in Fig. 10*b*. Besides the grain refinement, which results from this heat-treatment of the as-forged sample (*cf.* Fig. 9), the treatment revealed a new feature. Figure 10*c*, which is a composite photograph of a portion of the annealed segregate and adjacent matrix in Fig. 10*b*, at higher magnification, shows that the zone of the segregate, which extends from *X* to *Z*, varies in microstructure across its section. Between the matrix proper on one side of the segregate and the matrix on the opposite side there are three zones shown as structures *X*, *Y*, and *Z*. The differences in these structures are probably related to the variation in chemical composition as shown by the spectrographic traverses (*see* Figs. 5*b*–8*b*), and to variations in carbon, phosphorus, and sulphur content.

The marked variation in structure is probably caused by differences in carbon content associated with an inverse phosphorus content gradient. This suggestion is based on the reported inverse composition relationship of phosphorus and carbon in major segregates.[6]

The mechanism of formation of the segregates and the reason for their roundness in transverse section and rod-like shape longitudinally is indicated in the representative macrostructural sections of Fig. 11. In Fig. 11*a* the segregate (dark central zone) appears to be metal entrapped between the main spines or

Table VI

AVERAGE COMPOSITION OF SEGREGATES AND ADJACENT MATERIALS BY MICROCHEMICAL ANALYSIS

Element	3·5% Nickel Steel						2·5% Nickel Vanadium Steel					
	No. 7		No. 8		No. 9		No. 7		No. 8		No. 9	
	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix	Seg.	Matrix
C	0·39	0·35	0·40	0·37	0·39	0·37	0·44	0·42	0·44	0·42	0·44	0·42
S	0·103	0·034	0·105	0·032	0·058	0·034	0·073	0·026	0·073	0·026	0·067	0·026
P	0·106	0·032	0·051	0·032	0·064	0·034	0·090	0·028	0·089	0·030	0·095	0·031
Si	0·31	0·25	0·35	0·25	0·32	0·25	0·25	0·16	0·19	0·16	0·20	0·16
Mn	0·81	0·64	0·85	0·65	0·73	0·64	0·84	0·73	0·84	0·72	0·82	0·75
Ni	3·68	3·46	3·70	3·53	3·60	3·43	2·74	2·47	2·65	2·54	2·65	2·56
Cr	0·15	0·13	0·14	0·14	0·16	0·16	0·10	0·09	0·10	0·06	0·10	0·09
Mo	0·14	0·10	0·11	0·10	0·11	0·09	0·10	0·07	0·12	0·07	0·10	0·07
V	...	...	...	...	...	...	0·18	0·12	0·21	0·11	0·19	0·13

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arms of the dendrites, which lie at all angles round it. The darkly etching segregate is connected with the interdendritic material, which etches similarly and has a microstructure that cannot be distinguished from the segregate. Spectrographic evidence suggests that the variation in alloy content of the interdendritic material is only slightly less marked than in the segregate proper. The straightness of the segregate in longitudinal section is again brought out by Fig. 11*b*. although its continuity in this instance is broken by the intrusion of a dendrite at its lower end.

The concentration of non-metallic inclusions is evident in Fig. 12, which shows longitudinal sections of tensile test pieces from a segregate and its adjacent matrix. The occasional very low elongation and impact value of segregates, already mentioned, is considered to be associated with the occurrence of inclusions in the segregate at the surface of the tensile specimen or at the root radius of the notch in an impact test piece, rather than with abnormalities in composition. The occurrence of inclusions at the surface may be due to irregular distribution in the main spine of the aggregate (although there is a general tendency for inclusions to run down the centre of the segregate) or to the presence of interdendritic arms, which contain concentrations of inclusions and branch from the main segregate.

The effect of the non-metallic inclusions on the mechanical properties of the segregates is probably twofold. Firstly, if the space occupied by the non-metallic inclusion is considered as a cavity only, the effect would be to cause stress concentrations, the order of which would depend upon the shape and size of the cavity and particularly upon the radius of the ends and the relation between the direction of stress and the main dimensions of the cavity.[8] Secondly, the presence of the non-metallic particle, assuming adhesion across the steel/inclusion interface, might, because of the differences in elastic and plastic properties between itself and the surrounding steel, affect the strain behaviour of the latter under stress. Although the second of these conditions will modify the stress 'field' caused by the inclusion cavity,[9] it is to be expected that an inclusion at the free surface of a test piece under stress will provide a nucleus for a local stress redistribution from which fracture will start. Such inclusions may constitute the equivalent of Griffith's cracks in metals.[10]

The size, shape, and position of the inclusions relative to the stress, and their composition are important factors. The composition determines the final shape of the inclusions in the steel by reason of its flow characteristics when the steel is being forged, *e.g.*, it is probable that silicate inclusions (which are generally thinly drawn out and pointed at both ends) are more dangerous than sulphide inclusions, which are rounded at their ends.

CONCLUSIONS

Segregates in the two alloy steels examined (a 3·5% nickel steel and a 2·5% nickel–vanadium steel), have shown the following general characteristics :

(1) There is a hardness gradient across each segregate at a higher level than that of the matrix surrounding the segregate. A difference in hardness between segregate and matrix persists in all hardened and tempered samples, whatever the hardness level.

(2) The greater hardness of segregates by comparison with their adjacent matrices is reflected in their higher proof and maximum stresses. Their elongation and notched impact values are generally lower, and in some cases markedly so.

(3) There is a composition gradient across each segregate, rendering them more highly alloyed in nickel, vanadium, and molybdenum than the adjacent matrix. There is also a general increase in carbon, sulphur, and phosphorus content (particularly the latter), but the precise gradient of composition of the metalloids has not been established.

(4) Macrostructural differences across the width of segregates have been observed. These are probably related to the composition variations. Segregates, however, contain more non-metallic inclusions than the adjacent matrix. The incidence of these inclusions at the stressed surface of test specimens probably accounts for some of the very low values of maximum stress, impact value, and elongation reported. There is probably some physical similarity between the non-metallic inclusions and Griffith's cracks in other materials.

(5) Segregates appear to be the concentrated metal and, when liquid, are entrapped between the main spines of solidifying dendrites, which surround them. Metal in the interdendritic arms shows variations in hardness and composition comparable with those shown by segregates.

Acknowledgments

This paper is published with the approval of the Lords Commissioners of the Admiralty, but the responsibility for any statements expressed rests solely with the authors. The authors thank Mr. F. G. Barker, who encouraged the work and was most helpful in discussion of the results. Mr. Whalley is thanked for the work on microchemical tests, and Mr. Oldfield for carrying out the spectrographic traverses.

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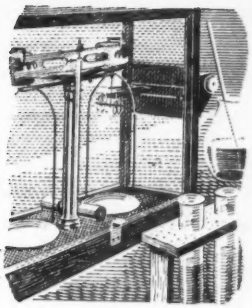
BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Corrosion of Steel Railway Sleepers: Final Report

By J. C. Hudson, D.Sc., D.I.C., F.I.M.

SYNOPSIS

The wastage, caused by rusting and abrasion, of copper-bearing steel sleepers has been compared with that suffered by ordinary mild-steel sleepers in service tests lasting up to 14 years and made at five places on the British Railways (Western Region). Except in a railway tunnel, the copper-bearing steel was between 20 and 70% better than mild steel. Ordinary mild-steel sleepers, weighing 150 lb., should last for about 10–100 years, according to the locality, before they lose one-quarter of their original weight. Under normal circumstances, therefore, the resistance of steel sleepers to rusting is adequate, but it can be appreciably increased, if desired, for sleepers laid in the open by using copper-bearing steel.

Introduction

The liability of steel to rust is one of the factors that determines the practical value of steel railway sleepers. In 1932, the Corrosion Committee began a series of tests to ascertain how far the life of steel sleepers in service was affected by rusting and whether this rusting could be reduced by the addition of small amounts of copper to the steel used to make the sleepers.

Two batches, each of about 120 similar sleepers, were manufactured, in one case from ordinary steel, and in the other from steel containing 0·5% of copper.* Sets of about 20 sleepers of each type were laid in various parts of the line; reports on their behaviour during the first five years' service have already been published.†

EXPERIMENTAL DETAILS

Manufacture of the Sleepers

The sleepers were of the composite type, consisting of a rolled- and pressed-steel sleeper plate carrying cast-iron chairs (*see* Fig. 1). The chairs were cast in position and secured to the plate by cast-iron lugs passing through snug holes in the plate. This design of sleeper is now obsolete, because the joint between the chair and plate proved unsatisfactory.

Both types of sleeper plate were rolled from the same 75-ton cast of basic open-hearth steel, the necessary copper additions being made to some of the ingots. The final trough section, from which the sleepers were pressed, measured approx. 8½ in. across the flats and was 3 in. deep and ⅜ in. thick. The sleeper was 8½ ft. long and weighed about 150 lb., or 240 lb. with the two cast-iron chairs. The analyses and mechanical properties of the steel sleeper plates are given in Table I.

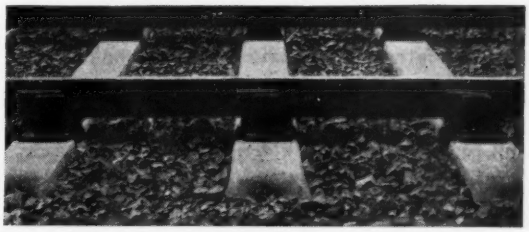


Fig. 1—Steel sleepers under service test at Wednesbury

* This copper content is rather higher than the minimum (about 0·3%) now known to be necessary to ensure the maximum increase in corrosion resistance.

† Second Report of the Corrosion Committee, *Special Report No.* 5, p. 132, 1934; Third Report *ibid.*, *Special Report No.* 8, p. 52, 1935; Fourth Report *ibid.*, *Special Report No.* 13, p. 48, 1936; Fifth Report *ibid.*, *Special Report No.* 21, p. 69, 1938: The Iron and Steel Institute.

Paper MG/BB/43/50 of the Atmospheric Corrosion Sub-Committee of the Metallurgy General Division of the British Iron and Steel Research Association, received 9th April, 1951. The views expressed are those of the author and are not necessarily endorsed by the Sub-Committee as a whole.

Dr. Hudson is Head of the Association's Corrosion Laboratory, Birmingham.

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Table I

ANALYSES AND MECHANICAL PROPERTIES OF THE SLEEPER PLATES

	Ordinary Mild Steel	Copper-Bearing Steel
General analysis, %	C 0·21, Mn 0·57, Si 0·06, P 0·019, S 0·028	
Copper content, %	0·05	0·45
Yield point, tons/sq. in.	16·9	17·4
Breaking load, tons/sq. in.	29·1	29·5
Yield ratio, %	58	59
Elongation on 8 in., %	29	27
Reduction in area, %	56	56

The sleeper plates were dipped in hot tar whilst they were still warm from pressing. The average thickness of the tar coating was approx. 2 mils (coating weight 4 oz. per sleeper). Each sleeper was weighed at the works, both before and after casting on the chairs. This was done on a large beam balance against dead weights, and the accuracy achieved was of the order of a few tenths of an ounce.

Test Conditions

The sleepers were divided into five batches, each comprising 20 or 24 sleepers of each steel, which were placed in service during the latter half of 1932 at five different localities on the Great Western Railway. The exposure sites were selected as follows, to represent a range of typical permanent-way conditions :

Aldermaston—The atmosphere is rural but the conditions were exceptional because the sleepers were laid in the down line immediately behind a water trough, so that they were thoroughly wetted every time a locomotive took up water.

Cholsey—The sleepers were laid in the up relief line. The atmosphere is rural and but mildly corrosive.

Dawlish—The sleepers were laid in the down main line immediately below the parapet of the sea wall; from time to time they were subjected to salt spray from rough seas.

Severn Tunnel—The sleepers were laid in the up main line between the mouth of the tunnel and the upward shaft at the Pilning end. This part of the tunnel is frequently full of smoke and the conditions are exceptionally severe.

Wednesbury—The sleepers were laid in the down main iine, near a chemical works where the atmosphere is often laden with acid fumes.

At all sites the sleepers of ordinary and copper-bearing steel were laid alternately in the track, to eliminate any positional effect.

RESULTS

Visual Inspections

The various stretches of sleepers were inspected in the track from time to time. In the Severn Tunnel, where the sleepers became covered with mud, accurate observations were impracticable.

Although the tar coating on the sleeper plates was thin, it seemed to afford considerable protection, and rusting was generally observed to begin in the middle of the plate where the coating was damaged by the boots of men walking along the line. Even after $2\frac{1}{4}$ years' service at Wednesbury, rusting was found to be confined to about the middle 2 ft. of the plates within the 4-ft. way, to the ends of the sleepers, and to the side beading in contact with the ballast. Grease dropped from axle boxes seemed to have helped to protect the ends of the sleepers outside the 4-ft. way, because the tar coating was fairly intact here. Rust samples scraped from sleepers at Wednesbury were found to contain about 14% of oil, and an oil content of the same magnitude was found in rust samples from the Dawlish sleepers, probably because shunting is carried out near both stations. No oil was detected, however, in rust samples from Aldermaston and Cholsey.

Systematic comparisons of pairs of adjacent sleepers showed that the copper-bearing steel plates were generally less affected by corrosion than those of ordinary steel.

After periods, which varied with the conditions of service, some of the chairs were found to have worked loose. The resulting play between the chair and the sleeper plate undoubtedly led to excessive loss of metal, both because of mechanical abrasion and because of increased corrosion in the crevice between the cast-iron chair and the steel plate. Eventually the pounding of the steel beneath the chair seatings by traffic on the line led to cracking of some of the sleeper plates and made it necessary to conclude the tests. As this report is concerned with the corrosion of sleeper plates rather than with metallurgical

Table II

SCHEDULE OF TESTS ON STEEL SLEEPERS

Locality and Date of Laying	Date of Removal	Test Duration, yr.	No. of Sleepers of each Steel Removed
Aldermaston (20.11.32)	19. 1.36	3·2	6
	3.10.37	4·9	6
	15.10.39	6·9	12
Cholsey (6.11.32)	5. 1.36	3·2	6
	19. 9.37	4·9	6
	23. 3.47	14·4	12
Dawlish (26.9.32)	13. 1.36	3·3	6
	4.10.37	5·0	6
	7.10.42*	10·0	8 or 7
	13. 4.44	11·5	4 or 5
Severn Tunnel (17.7.32)	20. 1.35	2·5	7
	12. 1.36	3·5	6
	14. 2.37	4·6	7
Wednesbury (24.7.32)	12. 1.36	3·5	6
	10.10.37	5·2	6
	20.12.46	14·4	12

* Average date—individual sleepers were removed at intervals between 1.7.42 and 16.11.42

problems connected with sleeper design, this cracking will not be discussed in detail, but the loosening of an appreciable proportion of the chairs must have caused a considerable increase in the observed average loss in weight of the sleeper plates. It is not possible to assess what proportion of the loss is due to this cause but, because of this factor, any estimates of the resistance of steel sleepers to corrosion based on the data presented in this report are conservative.

Quantitative Results

The original intention was to remove one quarter of the sleepers and chairs for cleaning and re-weighing after periods of exposure of 3, 5, 10, and 15 yr., respectively, except those in the Severn Tunnel, where three periods of exposure were contemplated. The outbreak of war in 1939 and the development of looseness in some of the chairs, made it necessary to alter this schedule to that given in Table II.

The results of the loss in weight determinations on the sleeper plates are shown graphically in Fig. 2; the figures given are averages for five or more plates. Some variation occurred between the sleepers of the same batch, as will be discussed later.* The final weighings were made after the sleepers had been carefully cleaned by chipping and wire-brushing. Inspections made on these occasions showed that in the main there was little serious corrosion of the upper surfaces, which had been protected by the original tar coatings reinforced by deposits of dust and grease. In some cases hot brand marks made at the mill were plainly visible even after 14 years' service. Most of the loss in weight seemed to have occurred on the underside of the sleepers in contact with the ballast, where rust of the scaly type up to $\frac{1}{16}$ in. thick was found. Some scoring of the steel by friction against the ballast had also taken place but, with a few exceptions, there was little marked pitting attributable to rusting alone.

DISCUSSION OF RESULTS

Positional Effect

A general relationship was found between the loss in weight of the sleeper plates and their position in relation to the rail joints. This is shown in Fig. 3,

* The actual figures are available in the records of the B.I.S.R.A. Corrosion Laboratory, together with numerous observations on the galling and loss in weight of the chairs.

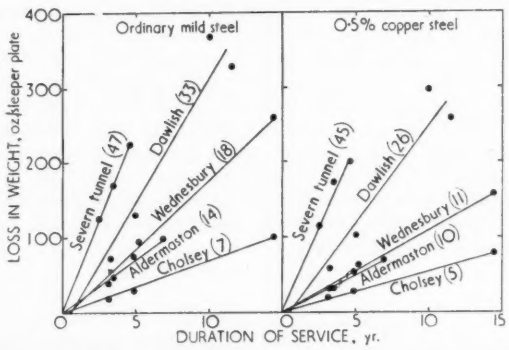

Fig. 2—Loss in weight of steel sleeper plates in service

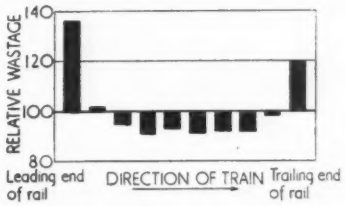

Fig. 3—Effect of position in rail on the wastage of steel sleepers

where the bars represent overall averages for all the batches of sleepers at all localities, with a few legitimate exceptions. Wastage is considerably greater near the 'leading' end of the rail, which is first hit by the oncoming trains; this is also true to a lesser degree for the sleepers at the 'trailing' end of the rail. The difference is probably caused by greater movement near the ends of the rail, under load. There was a greater tendency for the chairs to work loose near the ends of the rails and this may largely account for the heavier losses in weight of sleepers in these positions.

Comparison of Ordinary and Copper-Bearing Steel

Figure 2 shows that the loss in weight of the sleepers is roughly proportional to the duration of service. Some deviation from the straight-line law occurred at Dawlish but this may be attributed to exceptionally severe losses at the chair seatings at this site. The most probable straight lines fitting the results are shown in Fig. 2, together with the values of their slopes expressed in oz./sleeper/yr.; except at Dawlish the intercepts on the axes are negligible. The losses in weight over the maximum period of exposure at each station are given in Table III together with estimates, based on the equations for the straight lines in Fig. 2, of the times that would elapse before sleeper plates of each steel had suffered a wastage of one-quarter of their original weight (150 lb.). The results show that, except in the Severn Tunnel, sleeper plates of copper-bearing steel would have an appreciably longer life than sleeper plates of ordinary steel. The difference ranges from about 20% at Dawlish to nearly 70% at Wednesbury.

The fact that there was no appreciable difference between the two types of steel when exposed inside the Severn Tunnel agrees with earlier observations of the Corrosion Committee, which showed that the corrosion rates of ordinary iron and steels were substantially the same as those of the corresponding copper-bearing materials when exposed in the Dove Holes Tunnel.

Probable Lives of the Sleeper Plates

The results given in Table III show that, in general, the rate of corrosion of steel sleepers laid on the open track is not excessive. If the losses in weight are converted into average wastage over the whole surface of the plate (21·8 sq. ft.), the figures obtained for ordinary steel, in mils per year, are 0·48 at Cholsey, 0·98 at Aldermaston, 1·26 at Wednesbury, 2·00 at Dawlish, and 3·26 in the Severn Tunnel. Although a more corrosive atmosphere than that of Wednesbury could have been found, the results may be regarded

Table III

LOSSES IN WEIGHT AND ESTIMATED LIVES OF THE SLEEPERS

Locality	Test Duration, yr.	Loss in Weight, oz.		Estimated Service Life to 25% Wastage, yr.	
		Ordinary Mild Steel	Copper-Bearing Steel	Ordinary Mild Steel	Copper-Bearing Steel
Aldermaston (rural; water troughs)	6·9	97	67	42	61
Cholsey (rural)	14·4	99	77	86	113
Dawlish (marine)	11·5	328	258	19	23
Severn Tunnel	4·6	214	200	13	13
Wednesbury (industrial)	14·4	259	156	33	55

as a good indication of the general performance of steel sleepers up and down the country. They indicate that, according to the locality, the probable duration of service to 25% wastage is from 13 to 86 years for sleeper plates of ordinary steel.

These performances should suffice for practical purposes, but the results show that they could be improved by making the plates of copper-bearing steel, except, as already noted, for sleepers laid in tunnels. Moreover, subject to any limitations imposed by other practical factors, economies in the initial cost of sleepers might be effected by taking advantage of the superior rust-resisting properties of copper-bearing steel to reduce the weight of plate needed to ensure a desired service life.

These conclusions are based on the assumption that the service life of steel sleepers is determined by general wastage rather than by local perforation. This seems reasonable, because no unduly severe local attack, other than abrasion by ballast, was noticed on the great majority of the sleepers when they were cleaned after test. Two pits, approx. 0·4 in. in dia. and 0·15 in. deep, were found, however, on the underside of a sleeper removed from Dawlish after five years' service ; these had been caused by ballast action. Presumably perforation at one or two isolated points would not destroy the efficiency of a railway sleeper, provided it retained the necessary weight to anchor the line to the track.

CONCLUSIONS

The conclusions drawn from these tests may be summarized as follows :

(1) The rate of wastage of steel sleeper plates in service on the railway line is not excessive and varies from about ½ mil/yr. in a rural atmosphere to about 4 mils/yr. in a tunnel. Higher rates might be observed for track laid in a severely industrial atmosphere but, as a general rule, rusting should not prove a limiting factor in determining the service life of steel sleepers laid in Great Britain. The initial tar coating affords some protection to the sleepers. The effective life of the coating cannot be estimated because it varies with the local conditions ; in some parts of the track it may be prolonged by grease dropped from axle boxes.

(2) The service life of a 150-lb. sleeper of ordinary steel to 25% loss in weight by wastage is calculated to be 10–15 yr. in a railway tunnel. In the open air the life may be as much as 100 yr. in a rural atmosphere. These lives are calculated on the assumptions, supported by the experimental evidence, that the wastage, which includes abrasion losses and rusting, is directly proportional to the duration of service, and that pitting is not a serious factor.

(3) The rates of wastage, in all localities, other than the enclosed atmosphere of a tunnel, are reduced by the addition of copper to the mild steel used for the manufacture of the sleeper plate. The advantage resulting from the use of copper-bearing steel varies from 20 to 70% according to the locality. This could be put to practical use either by increasing the life of the sleeper plates or, where permissible, by decreasing the original weight of steel needed to ensure a stipulated life.

Acknowledgments

The Corrosion Committee wish the author to express their thanks to British Railways (Western Region) and to Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., for the provision of facilities and test materials. The author has pleasure in acknowledging considerable assistance received in the conduct of the experimental work from the Chief Engineers of the former Great Western Railway, the late Mr. R. S. Carpmael, Mr. A. J. Quartermaine, C.B.E., and members of their staffs, and also from the late Mr. F. F. Hunting, Mr. N. Gray, Mr. N. L. Tomlinson, and members of the Port Talbot Laboratory of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd. (now the Steel Company of Wales Ltd.). He is indebted to Mr. C. F. Insell, the G.W.R. Inspector at Port Talbot during the period of the tests, for guidance in the assessment of the mechanical condition of the chairs and sleepers, and to Mr. T. Henry Turner, at the time Chief Chemist and Metallurgist of the London and North Eastern Railway, for the analysis of rust samples.

The Kinetics of the Reduction of Iron Oxide above 1400° C.

By T. E. Dancy, Ph.D., D.I.C., A.R.C.S.

SYNOPSIS

An apparatus has been developed for the study of the very rapid reduction of FeO and Fe_3O_4 by carbon in molten pig iron. Oxide attack of the refractory was prevented by using a spinning crucible, and the reaction was followed by cinematographic recording of a low-inertia pressure gauge. The apparent activation energy of the reduction of FeO is − 43,100 cal./mol, and of Fe_3O_4 is − 37,300 cal./mol. The FeO reduction behaved as if of the first order, but only the initial part of the Fe_3O_4 reduction behaved thus. Temperature coefficients determined from activation energy and from ' order of reaction ' curves showed reasonable agreement.

SAMPLES of burden taken from blast-furnaces[1,2] have shown that incompletely reduced ore persists well down into the bosh, and possibly even to the hearth zone. The final stage of the reduction of ore is thus brought about when slags rich in iron oxide pass over coke or come into contact with carbon dissolved in iron. Saunders and Tress[3] showed that ' direct ' reduction of iron ores by many forms of carbon was very fast at temperatures above 900° C. Their studies of these reactions up to 1450° C. showed that the rates of reduction by coke fell off with increasing deoxidation, but where reduction was by carbon dissolved in the iron, intimate contact with the ore made the carbon particularly effective.

It seemed likely that the mechanism of the latter reaction might be of importance in the final stages of deoxidation of ores ; accordingly, the rate at which this reduction varied with temperature has been studied. When magnetite ore is used in the burden, some may remain almost unreduced until the tuyere or hearth zone is reached ; the rate of reduction of Kiruna magnetite by carbon in molten pig iron was therefore studied, in addition to that of ferrous oxide. From the results of these experiments the temperature coefficients of the reactions, and their activation energies, were determined. Some information concerning the mechanism of the reaction was also obtained.

EXPERIMENTAL DETAILS

Apparatus

Special precautions are needed in the study of any reaction involving ferrous oxide or ferrous oxide slags at high temperatures, to minimize reaction with the container. Magnesia is the most suitable common refractory,[4] as it forms no low-melting-point eutectic with FeO ; however, even recrystallized magnesia will rapidly absorb the molten oxide. Taylor and Chipman,[5] when studying equilibria between ferrous oxide slags and liquid iron, used a magnesia crucible coated with a very fine magnesia slip, which made it almost impervious. The iron was heated by induction, and further protection of the crucible was obtained by rotating it ; this allowed the slag to remain in the parabolic depression in the surface of the iron, since it would spread only until it had reached a certain minimum film thickness.

Initial experiments in this laboratory showed that if a crucible containing molten iron with a slag layer on the surface was rotated, most of the slag spun out to the walls and remained there because it wetted the refractory. However, a small amount of slag dropped into the already spinning crucible would remain in the centre, since it had a lower rotational energy and, once established there, no force acted on it to move it to the side. A section of a crucible, showing slag on iron, is seen in Fig. 1. Further experi-

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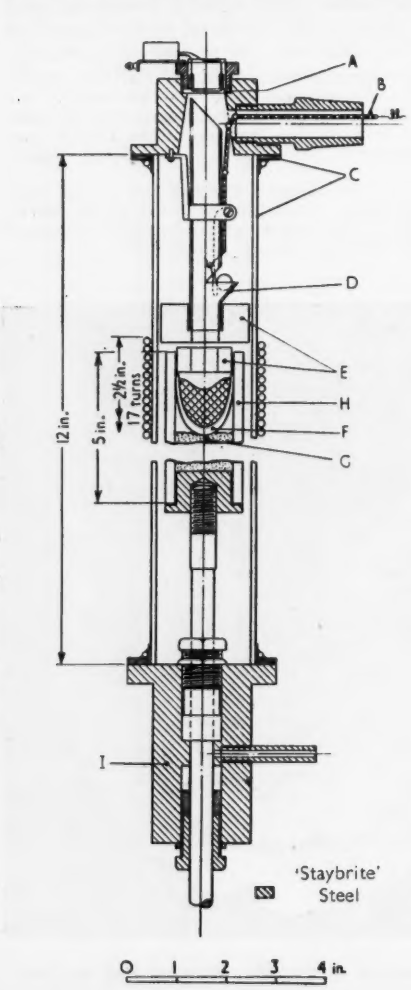
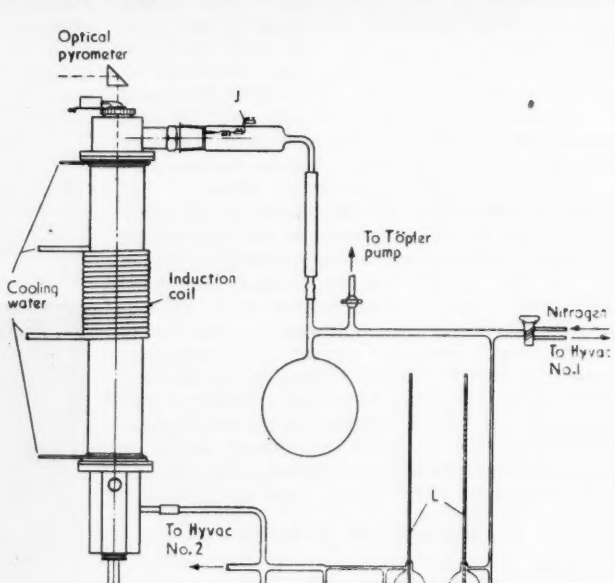
Dr. Dancy is a Scientific Officer of the British Iron and Steel Research Association, working at the Blast-Furnace Research Laboratory of the Imperial College of Science and Technology, South Kensington.

Fig. 1—Section of crucible, showing slag on iron

(a) (b)

Fig. 2—Crucible supports after addition of ferrous oxide to molten iron: (*a*) with spinning; (*b*) without spinning





A. Silica window with heater
B. Lead to sample-dropping device
C. Silica tube with metal flanges
D. Silica sample chute
E. Magnesite radiation shields
F. Magnesia crucible
G. Magnesia powder
H. Triangle *R* crucible support
I. Gland system with asbestos/graphite packing
J. Platinum wire sealed through glass
K. Needle valve leak
L. Mercury barometers
M. Capsule pressure gauge

Fig. 3—Details of apparatus, showing (*a*) reaction tube assembly, (*b*) complete layout

ments showed that, although vortices were formed in the iron if the crucible was spinning slightly eccentrically, any added slag would still remain in the centre. The speed of rotation used in these experiments was much higher than that used by Taylor and Chipman, because the diameter of the crucible was only 1 in. Figure 2 shows crucible supports after adding 1 g. of ferrous oxide to the molten iron, with and without spinning. The discoloration of the refractory is evident in Fig. 2*b*.

Commercially manufactured magnesia crucibles would not withstand ferrous oxide attack, owing to their high porosity, and did not have the mechanical strength to contain the spinning melt. They also cracked under the thermal shock of rapid induction heating. Magnesia crucibles were therefore made in the laboratory,[6] by embedding a graphite former in graded, fused magnesia powder, and heating it to about 3000° C. by induction. These crucibles had a continuous fused inner surface, and had good thermal and mechanical strength.

The reaction tube assembly, shown in Fig. 3, allowed a sample of iron oxide to be dropped into a spinning crucible, containing molten pig iron, while the reactants were in a totally enclosed system at reduced pressure. The axle attached to the crucible support passed through two glands, and space between these was maintained at approximately the same pressure as in the reaction system by adjusting the leak *K* and by observing the mercury barometers *L*. The iron was heated by high-frequency induction at 500 Kc. from a 2·5-kVA. generator.

The sample of iron oxide was dropped into the melt by fusing a supporting iron wire, and the instant of dropping was indicated by a light on the instrument panel. The increase in pressure in the system, caused by the reaction, was indicated on a low-inertia capsule pressure gauge (a modified air-speed indicator), and was recorded by a ciné-camera which simultaneously photographed a stop-watch.

The temperature was measured by a Cambridge optical pyrometer sighted (*via* a glass prism) through the silica window. Corrections for the emissivity of the iron and absorption by the prism and window were determined directly by a series of independent experiments using a bare Pt/Pt–Rh thermocouple and a Honeywell-Brown electronic temperature recorder, which indicated up to 1700° C. and registered the temperature before the thermocouple was contaminated or destroyed by the pig iron. Corrections above 1700° C. were estimated by extrapolation; check readings were obtained up to 1450° C. by sighting the optical pyrometer, both directly and through the window and prism, at a black-body source, and using a calculated emissivity correction (*see* Fig. 10).

Materials

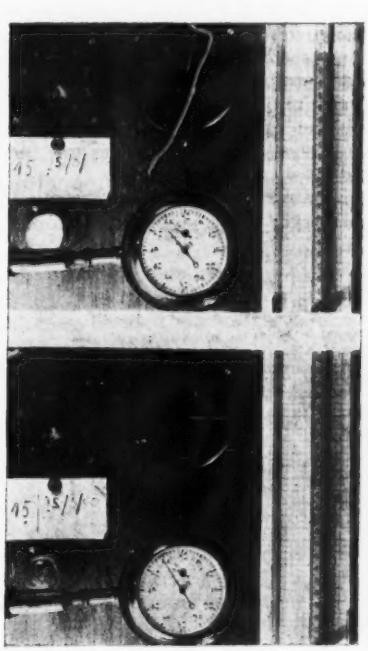
Walloon pig iron[3] (iron/carbon eutectic, 4·3% of carbon) was used for all the experiments. This material showed nearly complete fusion at 1150° C. Small ingots (approx. 50 g.) were prepared, and a fresh sample was used for each experiment. Samples taken at random were nearly constant in composition.

The ferrous oxide used was prepared from carbonyl iron powder (99·7% of Fe, 0·025% of O) and pure ignited ferric oxide, which was prepared from re-sublimed ferric chloride by precipitation with ammonium carbonate followed by ignition in air at 900° C. Weighed amounts of the iron and ferric oxide (to yield stoichiometric FeO) were ground together and sealed *in vacuo* in a silica tube; the tube was then heated to 1100° C. and quenched in cold water. The product was only very slightly magnetic in the field of a powerful magnet, and its X-ray diffraction pattern did not indicate the presence of Fe_3O_4 or Fe. The product was lightly sintered, and could be broken into lumps suitable for the experiments.

A sample of high-grade Kiruna ore (> 98% of Fe_3O_4) was used for the magnetite experiments, and its X-ray diffraction pattern showed no major impurities.

Method

After placing the pig-iron sample in the crucible and the iron-oxide sample (about 0·5 g.) on the chute, the system was closed, using silicone vacuum grease on the flanges. The lead to the dropping device was connected and the reaction tube was attached to the remainder of the system, which was then evacuated. When the iron was at the required temperature, pure nitrogen was added, bringing the pressure to about 10 cm. (absolute), and the gland pressure was adjusted simultaneously. After the crucible-spinning mechanism had been set at 400 r.p.m., filming of the instruments (8 frames/sec.) was started and the oxide sample was dropped into the iron. When the reaction had ceased a gas sample was taken with the Töpler pump, and the apparatus was filled with nitrogen.



(a)

(b)

Fig. 4—Two frames of a film record: (*a*) at moment when indicator light was extinguished; (*b*) one second later

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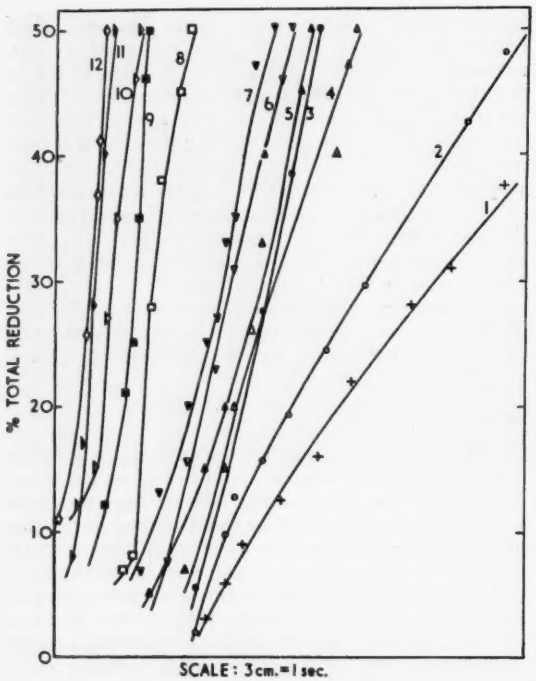

Fig. 5—Curves of % total reduction *vs.* time, to 50% reduction, for FeO experiments (*see* Table I)

EXPERIMENTAL RESULTS

The film records were studied under a low-power microscope. Figure 4, a print of two frames, shows (*a*) the point at which the indicator light was extinguished, and (*b*) one second later. Time intervals could be estimated to 0·1 sec., and pressure-indicator readings to 10 m.p.h. (equivalent to about $\frac{1}{2}$ mm. of Hg). The size of sample and the volume of the system were chosen to give a pressure increase of about 5 cm.

Carbon monoxide was the only gas produced by the reduction of either of the ores at these temperatures.

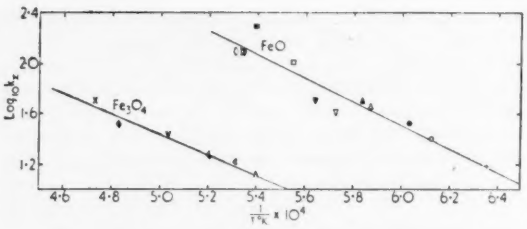

Fig. 7—Graphs of $\log_{10} k_x$ plotted against 1/T

However, the lump of oxide was disrupted when it first fell into the molten iron, and some of the smaller particles were blown out of the crucible. As heating was by induction, only the region at the crucible was at high temperature, and thus any material that left the crucible could take no part in the reaction. This view was supported by the fact that no measurable quantity of CO_2 was formed. Moreover, after some experiments, small particles of oxide were found in the bottom of the silica tube, and oxide dust was collected on a filter plug in the exit from the reaction tube.

In spite of these losses it is possible to determine the rates of reaction, since it is implied from thermodynamic considerations[7] that the reduction of FeO or Fe_3O_4 will rapidly pass to completion in the presence of a large excess of carbon at high temperatures, and thus the flat portion of the pressure/temperature curves may be interpreted as 100% reduction. The present experiments, therefore, may be plotted similarly, on the basis of % total reduction against time (*see* Figs. 5 and 6).

Results for the FeO experiments were plotted to 50% reduction in Fig. 5, because only the initial part of the reaction was used in the determination of activation energy. Also, since the relative positions of the curves with respect to time were of no interest in this calculation, the lines have been separated in an empirical manner and arranged in order of decreasing temperature, so that the slopes could be more easily observed. Experiments 4, 7, 8, 9, and 11 were plotted up to 100% reduction in Fig. 6*a*, and were used in the determination of the order of reaction. The induction period, between the time of dropping the sample ($t = 0$) and the beginning of the reaction, was the actual time taken for the sample to reach the iron and heat to temperature. To compare the rates of these reactions at various temperatures, the steepest portion of the curves was assumed to be the initial reaction rate. The error in this assumption is not great, because the rate of reaction falls off only very slowly after the maximum

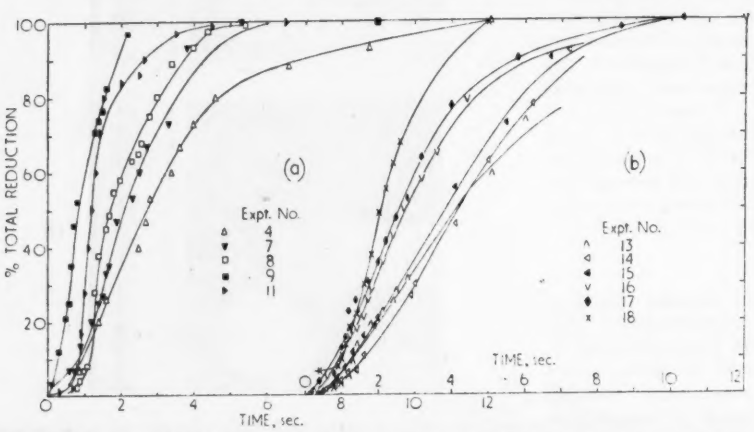

Fig. 6—Curves of % total reduction *vs.* time, to 100% reduction: (*a*) FeO experiments; (*b*) Fe_3O_4 experiments (*see* Table I)

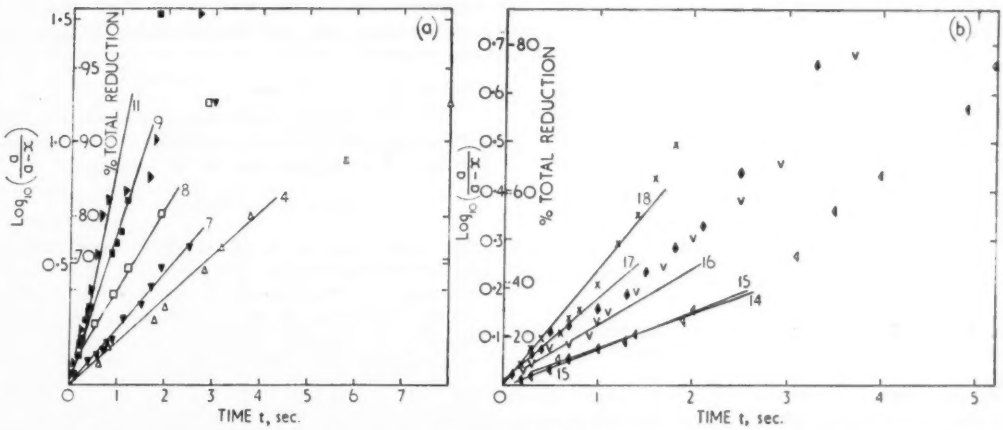

Fig. 8—Reaction-rate curves for first-order reactions: (*a*) FeO experiments; (*b*) Fe_3O_4 experiments

has been reached, and the maximum is reached before 20% of the reaction has occurred. Experiments 1 and 2 (Fig. 5) and 13 (Fig. 6*b*) are exceptions in which, although the initial parts of the curves are fairly steep, the rate soon falls off to become almost constant for the remainder of the reaction. The temperatures of these three experiments were below the melting points of the respective oxides and, therefore, after the surface layers of oxide had reacted, the continuation of the reaction was possibly retarded by a layer of iron.

DISCUSSION

Apparent Activation Energy

The influence of temperature on reaction velocity is expressed by the Arrhenius equation :

$$\frac{d\log_e k}{dT} = \frac{E}{RT^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table I

MAXIMUM GRADIENTS OF CURVES OF % TOTAL REDUCTION *vs.* TIME

Experiment No.	Temperature of Experiment, °C.	Maximum Slope, k_x
FeO Experiments		
1	1300	15·2
2	1360	25·0
3	1385	33·4
4	1430	45·5
5	1440	50·0
6	1475	40·0
7	1500	50·0
8	1530	100·0
9	1580	200·0
10	1595	125·0
11	1595	125·0
12	1610	125·0
Fe_3O_4 Experiments		
13	1580	12·5
14	1610	16·2
15	1650	17·6
16	1715	27·1
17	1800	32·2
18	1840	50·0

where k is the velocity constant. This equation can be applied not only to homogeneous gas reactions, but also to reactions in solution and to heterogeneous processes. It is most useful in its integrated form :

$$\log_e k = -\frac{E}{RT} + \text{const.}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

and when applied to a reaction will give a linear relation between $\log_e k$ and $1/T$, provided that the factors controlling the rate of reaction are the same over the temperature range studied. From the slope of this curve the value of the activation energy E may be calculated.

The true activation energy cannot be calculated from the results of the present experiments, because the reaction is of an ill-defined heterogeneous nature. However, using the same method, an apparent activation energy may be obtained which will express, in cal./mol, the algebraic sum of the activation energy of the rate-determining step of the reaction, and heat terms determined by changes in the properties of the system with temperature.

Since only the slope of the graph of $\log_e k$ *vs.* $1/T$ is required, it is not necessary to know the absolute value of the velocity constant, and any measure of the reaction rate that is proportional to the velocity constant may be used. The maximum slopes k_x of the curves in Figs. 5 and 6 were used for this purpose ; the values of k_x are given in Table I. Graphs of $\log_{10} k_x$ *vs.* $1/T$(° K.), for FeO and Fe_3O_4, are shown in Fig. 7 ; a linear relationship is obtained in both cases.

Since, from equation (2) :

$$E = -2{\cdot}303R\frac{\Delta\log_{10} k_x}{\Delta(1/T)}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

the apparent activation energy for the reaction between ferrous oxide and carbon in molten pig iron is — 43,100 cal./mol, and for magnetite is — 37,300 cal./mol. Both values were determined from the statistically calculated ' best ' lines.

The factors that contribute towards these high apparent activation energies should be considered. During the reactions, as much as 20 ml. of carbon

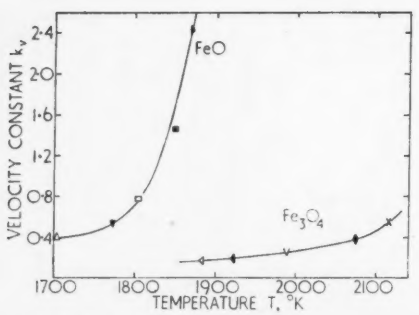

Fig. 9—Graph of velocity constant *vs.* temperature, for FeO and Fe_3O_4 experiments

monoxide escaped, per second, from each square centimetre of reacting interface. The manner in which the surface was broken up by this gas evolution, and the rate at which the reactants reached the interface, could be influenced to a great extent by the viscosity and surface tension of the components. The heat terms from the changes of these or other properties, combined with the activation energy of the rate-controlling step, might account for the high values obtained.

Order of Reaction

When the rate of a reaction is proportional to the concentration of the reactant at any instant, the reaction will be of the first order, and it may be deduced that:

$$k_v = \frac{1}{t}\log_e\left(\frac{a}{a-x}\right),$$

where k_v is the velocity constant, a is the initial concentration of the reactant, and x is the amount of reactant decomposed after time t. For a first-order reaction, therefore, a plot of $\log_e\{a/(a-x)\}$ against t will give a straight line. For a second-order reaction, the relation:

$$k_v = \frac{1}{t}\cdot\frac{x}{a(a-x)}$$

will apply when t plotted against $x/a(a-x)$ gives a straight line.

For selected FeO experiments over the range 1430–1595° C. (*see* Fig. 6*a*), values of $\log_{10}\{a/(a-x)\}$ plotted against t (Fig. 8*a*) gave a series of straight lines, although only up to 80% reduction. The lines do not pass through the origin, owing to the error in estimating the true zero time, which can only be determined by extrapolation. Values of $x/a(a-x)$ plotted against t did not give straight lines.

The reduction of ferrous oxide under these conditions is at least bimolecular, but there is a large excess of carbon present, so that the rate would not be influenced by the small decrease in carbon concentration. The reaction must therefore be considered pseudo-unimolecular, and the fact that it is kinetically of the first order supports this view.

A similar treatment of the results of the reduction of magnetite (*see* Fig. 6*b*) does not yield such conclusive results, because the reaction-rate curves (Fig. 8*b*) only follow a first-order relation for less than 30% of the reaction, over the temperature range studied (*i.e.*, 1610–1800° C.). The second-order relation does not give straight lines for any part of the reaction.

Temperature Coefficient

The temperature coefficient of a reaction is defined as the ratio of the velocity constant at one temperature to that at a temperature 10° C. higher, *i.e.*:

$$\text{temperature coefficient} = \frac{k_v T + 10}{k_v T},$$

and since values of k_v at various temperatures could be determined from the slopes of the 'order of reaction' curves (Fig. 8), the temperature coefficients of the reduction of these samples were calculated. In Fig. 9, velocity constants are plotted against temperature for both reactions; the value of k_v obtained from experiment 9 was shown to be unreliable (Fig. 7), and has therefore been neglected when drawing the FeO curve. The temperature coefficients for 50° K. temperature intervals were calculated by taking the 5th root of the rise in k_v for $T + 50°$ K., and are given in Table II, together with the temperature coefficients calculated from the graphs of $\log_{10}k_x$ *vs.* $1/T$. The agreement between the two methods would not be obtained if the first-order relation is incorrectly assumed to be applicable to these reactions.

Although the reduction of magnetite was carried out over a slightly higher temperature range than that of ferrous oxide, the reaction is seen to proceed more slowly, and the fact that only the initial part of the reaction is of the first order may be because only this part is a single reaction, *i.e.*, $Fe_3O_4 + C \rightarrow 3FeO + CO$, whereas, in the later stages, the reaction $FeO + C \rightarrow CO + Fe$ is taking place simultaneously. Also, the latent heat of melting of Fe_3O_4 is high (142 ± 1 cal./g., m.p. 1597° C.),[8] and hence the melting of the magnetite may be a contributory factor in its rate of reduction. Ferrous oxide has a lower latent heat of fusion (104 cal./g., m.p. 1369° C.),[9] which is unlikely to influence the reaction significantly.

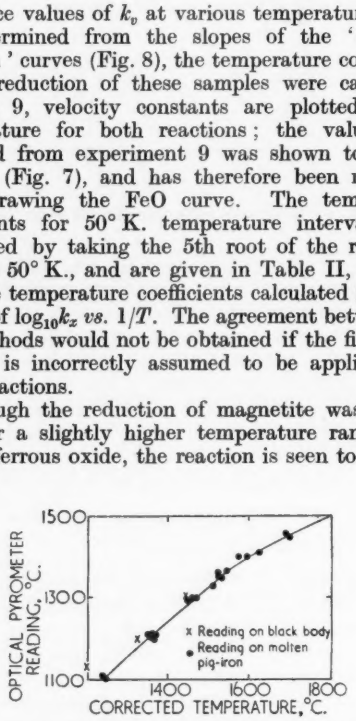

Fig. 10—Calibration of optical pyrometer

Finally, the nature of the apparatus is such that the power input necessary to maintain the iron at a high temperature is very large compared with the thermal energy absorbed by the reaction, and therefore any drop in temperature at the reaction interface must be small.

ERRORS

Figure 10 shows that the temperature readings are not likely to have an error greater than ± 10° C., and

Table II

COMPARISON BETWEEN CALCULATED AND GRAPHICAL VALUES OF TEMPERATURE COEFFICIENTS

Calculation			Graphical Method			
Temp. of Experiment, T° K.	Velocity Constant, k_v	Temp. Coefficient, $\frac{k_vT+10}{k_vT}$	Temp. of Experiment, T° K.	$\frac{1}{T}\times 10^4$	$\log_{10}k_x$*	Temp. Coefficient, $\frac{k_xT+10}{k_xT}$
FeO Experiments						
1700	0·410					
1750	0·475	1·03	1650	6·061	1·445	1·08
1800	0·750	1·09	1850	5·405	2·070	
1850	1·720	1·17				
Fe_3O_4 Experiments						
1900	0·180	1·036				
1950	0·220	1·046	1900	5·263	1·215	1·048
2000	0·275	1·043	2100	4·762	1·625	
2050	0·340	1·067				
2100	0·470					

* k_x = Maximum slope

the error between them is probably less than this. The greatest error in the determination of activation energy was in the estimation of the slope of the rate curves, and hence in $\log_{10}k_x$; therefore, the 'best' line for $\log_{10}k_x$ *vs.* $1/T$ was calculated for both series of points (*see* Fig. 7). Slopes of $-0{\cdot}94$ for FeO and $-0{\cdot}82$ for Fe_3O_4 were obtained. For FeO, the variance in the slope was 0·0089, and hence the standard deviation was $\pm 0{\cdot}094$; similarly, for Fe_3O_4 the variance was 0·0065, giving a standard deviation of $\pm 0{\cdot}080$. Therefore, the statistically calculated values for the activation energy are :

$$\text{FeO}: \quad E = -43{,}100 \pm 4300 \text{ cal./mol}$$
$$Fe_3O_4: \quad E = -37{,}300 \pm 3700 \text{ cal./mol.}$$

SUMMARY

The results and conclusions may be summarized as follows :

(1) The reduction of pure ferrous oxide and of pure magnetite, by carbon in molten pig iron, is very fast above 1400° C. The reduction of ferrous oxide is faster than that of magnetite at a given temperature, but the increase in rate with temperature is similar. In the lower part of the blast-furnace, this high rate of reaction is unlikely to be a controlling factor in the overall rate of reduction of iron ore, as the reaction will usually take place in the presence of slag.

(2) The apparent activation energy of the reduction of ferrous oxide is $-43{,}100 \pm 4300$ cal./mol, and for magnetite is $-37{,}300 \pm 3700$ cal./mol.

(3) The reduction of ferrous oxide is a first-order reaction up to 80% reduction in the range 1430–1595° C., and its mechanism is probably pseudo-unimolecular. The reduction of magnetite follows a first-order relation only up to 30% reduction from 1600–1840° C., probably because the reaction proceeds in stages.

(4) The temperature coefficient of the FeO reaction, calculated from the 'order of reaction' curves, is about 1·08 from 1430–1530° C., which is in agreement with the coefficient calculated from the graph of $\log_{10}k_x$ *vs.* $1/T$. The temperature coefficient of the magnetite reduction, calculated by either method, is 1·05 over the whole temperature range from 1510–1840° C. The agreement of the values as calculated by independent methods supports the validity of the treatment of the results.

(5) The experimental technique employed is satisfactory for the investigation of fast reactions, but was used at its limit in the higher-temperature ferrous oxide reductions. In addition, the spinning crucible can be used with small samples, to protect the refractory crucible from ferrous oxide attack at temperatures up to 1800° C.

Acknowledgments

The author wishes to express his appreciation to Dr. H. L. Saunders, Head of the Iron Making Division of the British Iron and Steel Research Association, for helpful advice in the course of the investigation, and for permission to publish this paper.

Thanks are also due to Dr. J. R. Rait, of Messrs. Hadfields, Ltd., who supplied a bar of 'Inert 92' steel, and to the Research Department of the Mond Nickel Co., Ltd., who provided the carbonyl iron powder used in these experiments.

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Determination of Hydrogen in Liquid Steel

By R. M. Cook, B.Sc.(Eng.), A.Met., and J. D. Hobson, B.Sc., A.Met., A.R.I.C., A.I.M.

SYNOPSIS

A comparison between two methods for the determination of hydrogen in liquid steel is given as a result of collaborative work between two laboratories. The methods employ a sealed mould and a quenched notched pencil, which have been developed in the respective laboratories. Results are given for 15 casts made by acid and basic open-hearth, and basic electric-arc processes, and sampled at the works with which the authors are associated. Satisfactory agreement is shown for comparative results obtained by the two methods.

In recent years reports[1, 2, 3, 4, 5] have been published on the determination of hydrogen in liquid steel. The modified notched-pencil test, described by Wells and Barraclough,[2] has been used by the Brown-Firth Research Laboratories for several years to control the hydrogen content during the manufacture of low-alloy and high-alloy steels by the electric-arc and acid open-hearth processes. The sealed-mould test, described by Speight and Cook,[3] has been developed by The United Steel Companies, Ltd., and has provided considerable data on the possible variation in the hydrogen content of steels made by basic open-hearth and electric-arc processes. From the data available for the hydrogen contents of similar steels, there appeared a slight difference in hydrogen content obtained by the two methods.

This difference has been investigated by a direct comparison of the two methods. The present authors have jointly sampled a number of heats at the works of Messrs. Samuel Fox and Co., Ltd., Messrs. Steel Peech and Tozer, and Messrs. Thomas Firth and John Brown, Ltd., and have analysed these samples for hydrogen by their respective methods.

SAMPLING AND ANALYSIS METHODS

Modified Notched-Pencil Mould Method

In this method[2] a sample of liquid steel is withdrawn from the furnace with a well-slagged sample spoon, is skimmed, and is poured into a special cast iron mould to act as a 'warmer.' The mould is opened and the pencil is discarded. A second sample of liquid steel is then taken in the same way, is killed with a small quantity of aluminium wire if necessary, and is poured into the mould. The mould is immediately opened and the notched-pencil sample is rapidly quenched in water from red heat.

A specimen (nominally $\frac{1}{2}$ in. dia. $\times$ $\frac{1}{2}$ in. long) from a section broken from the pencil is prepared by light grinding to remove surface scale. The sample is weighed, degreased, and hydrogen is determined by vacuum heating for 45–70 min. at 650° C., or for 3 hr. in the case of austenitic steels. Hydrogen is determined in the gases extracted by diffusion through a heated palladium tube attached to the extraction apparatus.

Pencil samples are stored in solid carbon dioxide at — 78° C until required for analysis, which is carried out with the minimum delay.

Sealed-Mould Method

A sample of liquid steel is withdrawn from the furnace with a well-slagged sample spoon, skimmed, and killed with aluminium wire.[3] The liquid steel is poured into a water-cooled mould, which is immediately sealed by a special cap. The mould and cap together are then immersed in water until they are cold.

The gas within the mould is first extracted, collected, and analysed for hydrogen. The mould is then opened and the steel sample is removed and is lightly ground to remove any surface scale. After degreasing and weighing, the sample is introduced into the extraction apparatus. The residual hydrogen is extracted by vacuum heating for approx. 1 hr. at 750° C., the evolved gas being collected and analysed for hydrogen by means of a modified Orsat type of apparatus. The hydrogen content of the original liquid steel is given by the sum of the hydrogen contents of the two fractions. Loss of hydrogen as water vapour during vacuum heating is prevented by passing the evolved gas over heated ferro-manganese.

Paper SM/BB/102/50 of the Gases and Non-Metallics Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 16th November, 1950.

Mr. Cook is in the Research and Development Department of The United Steel Companies Ltd., and Mr. Hobson is on the staff of the Brown-Firth Research Laboratories.

Table I

HYDROGEN DETERMINATIONS

Date	Works	Cast	Furnace	Quality	Stage	Hydrogen Content, ml./100 g.			
						Notched-Pencil Method		Sealed-Mould Method	
						Duplicates	Average	Duplicates	Average
8/11/49	*A*	1	Basic electric-arc	1% C, 1·4% Cr	Prior to tap	4·7	...	5·8 5·1	5·4
8/11/49	*A*	2	Basic electric-arc	1% C, 1·4% Cr	Prior to tap	4·7 4·3	4·5	4·2 4·4	4·3
15/11/49	*A*	3	Basic open-hearth	0·65% C	At melt	5·8 6·3	6·0	5·5 5·9	5·7
15/11/49	*A*	4	Basic open-hearth	0·4% C, 0·8% Ni	During boil	9·4 9·3	9·4	10·8 9·8	10·3
11/1/50	*A*	5	Acid open-hearth	1% C	During boil	3·3 3·6	3·4	3·4 3·6	3·5
11/1/50	*A*	6	Basic electric-arc	0·7% C	Prior to tap	5·5 5·5	5·5	4·6 5·1	4·9
26/1/50	*A*	7	Basic open-hearth	0·4% C, 0·8% Ni	During boil	6·4 5·8	6·1	6·2 5·9	6·1
21/2/50	*B*	1	Basic electric-arc	1·5% Ni,Cr,Mo	Prior to tap	4·8 4·7	4·7	4·5 4·9	4·7
2/3/50	*B*	2	Basic electric-arc	1% C, 1·4% Cr	Prior to tap	4·7 4·7	4·7	3·7 4·0	3·9
2/3/50	*B*	3	Acid open-hearth	0·3% C, 0·8% Mn, 0·7% Mo	Prior to tap	3·8	...	4·1	...
2/3/50	*B*	4	Acid open-hearth	0·3% C, 0·8% Mn, 0·7% Mo	Prior to tap	3·3	...	3·9	...
7/3/50	*B*	5	Basic electric-arc	0·6% C, 0·5% Cr, 1·7% Ni	Prior to tap	6·7 5·9	6·3	4·4 4·5	4·5
7/3/50	*B*	6	Basic electric-arc	2·5% Ni,Cr,Mo	Prior to tap	4·8 4·6	4·7	4·9 *	...
9/11/50	*C*	1	Basic open-hearth	0·12% C	Prior to tap	7·5 7·9	7·7	6·7 7·9	7·3
22/11/50	*C*	2	Basic open-hearth	0·15% C	Prior to tap	* 5·7	...	6·0 6·7	6·4

* These samples were unsatisfactory

RESULTS

In all, 15 casts of steel were sampled, covering a range of compositions, which included low-alloyed types made by the three processes—acid and basic open-hearth, and basic electric-arc. Samples were taken at various stages throughout the heats and were aluminium killed, except when the steel was ready for tapping. In almost every case the Brown-Firth Research Laboratories notched-pencil and the R.D.D. sealed-mould samples were taken from the same spoon of liquid steel. Duplicate samples were then taken in the same manner from a second spoon.

Table I gives results of the hydrogen determinations made by the two methods, together with data relating to the types of steel, methods of manufacture, etc.

DISCUSSION OF RESULTS

The maximum variation between duplicate determinations was 0·8 ml./100 g. for the notched-pencil tests and 1·2 ml./100 g. for the sealed-mould tests. Agreement between the two methods is on the whole satisfactory, and except in the case of cast *B*5, in which the Brown-Firth Research Laboratories returned the higher values, the maximum variation between average results is 0·9 ml./100 g. This maximum variation is shown for cast *A*4, which has an unusually high hydrogen content, and might, therefore, be expected to give rather variable results.

Since the results show no bias in favour of high results for one particular method, it may be concluded that neither method is liable to losses during sampling, and both, therefore, are satisfactory if carefully used by experienced operators.

For control purposes, the notched-pencil determination has the advantage of requiring a shorter time.

Acknowledgments

The authors thank the Directors of their respective firms for permission to publish these results, and the staff of the various melting departments for their help in obtaining the samples.

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XUM

Structural Transformations in the Tempering of High-Carbon Martensitic Steels

By K. H. Jack, M.Sc., Ph.D.

SYNOPSIS

New X-ray observations give direct evidence that the loss of tetragonality of martensite during the first stage of steel tempering is caused by the precipitation of a close-packed hexagonal iron carbide of composition near Fe_2C. It is proposed that this iron carbide should be named ϵ-iron carbide, because of its structural similarity to ϵ-iron nitride. The ϵ-iron carbide is formed as a coherent transitional phase in which relaxation of the Laue condition for X-ray reflection is a minimum in a direction normal to the (101) lattice planes. The existence of a simple orientation relationship between martensite and the hexagonal carbide is probable.

During the third stage of steel tempering, ϵ-iron carbide transforms to give a fine dispersion of very thin platelets of cementite, with the planes of the platelets parallel to the (001) lattice planes of the cementite structure. The observed X-ray diffraction pattern is markedly different from that of high-temperature crystalline cementite, as the Laue condition is completely fulfilled only in directions parallel to the (001) planes, and is relaxed in the [001] direction. Included among the strongest reflections are those corresponding to previously unidentified X-ray reflections observed by earlier investigators and ascribed by them to a new unknown iron carbide. With increasing tempering times, or at higher temperatures, the gradual growth and recrystallization of the cementite platelets are accompanied by reduction in the lattice strain of the matrix.

Each of the two stages of the transition of martensite to cementite (corresponding to the first and third stages, respectively, of steel tempering) can take place by relatively small movements of iron atoms, and the precise nature of these movements is suggested. The proposed structural changes are correlated with the well-known changes in hardness and specific volume of steel during tempering, and are supported by recent electron-microscope studies.

Cementite platelets similar to those observed in tempered martensites are also obtained in the low-temperature heat-treatment of carbonyl-iron powders.

Introduction

In past studies of the tempering of hardened plain carbon steels, use has been made of metallographic observations, magnetic measurements, hardness measurements, dilatometric and specific volume changes, the measurement of thermal effects, and changes in electrical resistance; and also of X-ray, electron-diffraction, and electron-microscope methods. Although no attempt is made here to review the voluminous literature, it is evident that, starting with a hardened structure consisting of tetragonal martensite and retained austenite, high-carbon steels undergo three structural changes during low-temperature tempering. Each stage is accompanied by characteristic changes in physical properties. The first stage occurs at about 80–160° C., and is accompanied by a marked decrease in volume, an increase in hardness, a slight decrease in magnetization, and an evolution of heat. The second stage, at 230–280° C., is accompanied by a small increase in volume, a large increase in magnetization, retarded softening, and an evolution of heat. The third stage involves decreases in magnetization and specific volume, and a marked softening; it occurs at about 260–360° C., but may overlap the second stage and may continue well above 360° C.

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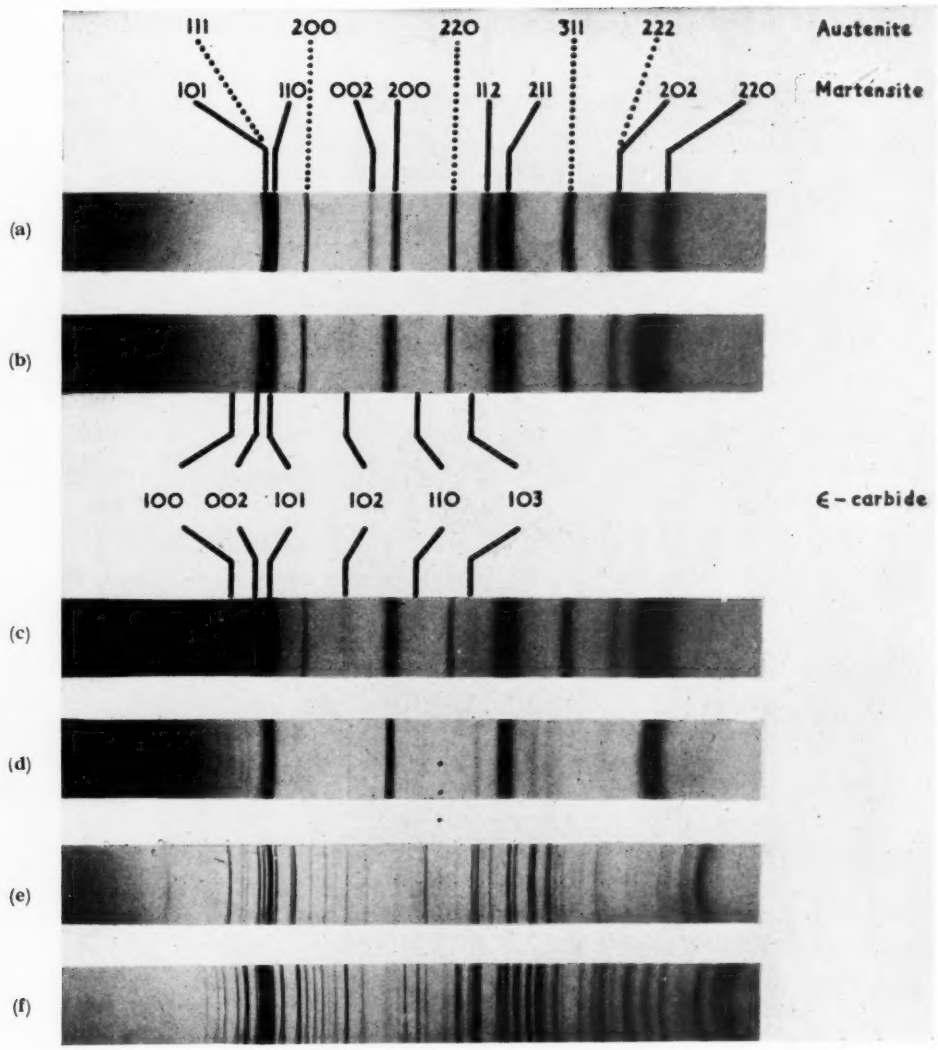
Antia, Fletcher, and Cohen[1] emphasize that the underlying phase reactions are time-dependent, and occur either isothermally or on heating to the tempering temperature. Faster rates of heating displace the ranges of maximum change to higher temperatures.

There is general agreement that the second tempering stage is the transformation of retained austenite. The exact natures of the first and third stages, which are associated with the decomposition of martensite into the ultimate aggregate of ferrite and cementite, have not previously been established, and are the main subject of the X-ray investigation described in this paper. Summaries of the results obtained have been published elsewhere.[22, 33]

PREVIOUS WORK

The Existence of a Transitional Iron Carbide

Honda and Nishiyama[2] suggested that the first stage of steel tempering is the transformation of tetragonal martensite (α') to cubic martensite, without precipitation of carbon but with a shift of the carbon atoms from the $\frac{1}{2}, \frac{1}{2}, 0$ and $0, 0, \frac{1}{2}$ octahedral interstices to the tetrahedral interstices at $\frac{1}{2}, \frac{1}{4}, 0$ and equivalent positions. Hägg[3] showed that evidence for the existence of cubic martensite is questionable, and that the observed changes in lattice dimensions are more plausibly explained by the rejection of carbon from α' solid solution. Cohen and co-workers[1] adopt Hägg's mechanism, and consider that the first tempering stage involves the formation of ferrite and a precipitated carbide phase too finely divided to yield an X-ray diffraction pattern. They show that the transition carbide is not cementite because :



(a) As quenched
(b) 5 days at 120°C.
(c) 40 days at 120°C.
(d) 12 days at 250°C.
(e) Crystalline cementite
(f) Iron percarbide

Fig. 1—X-ray powder spectra of martensitic steel (specimen *A*, 1·3 wt.-% of C) tempered at 120° and 250°C.

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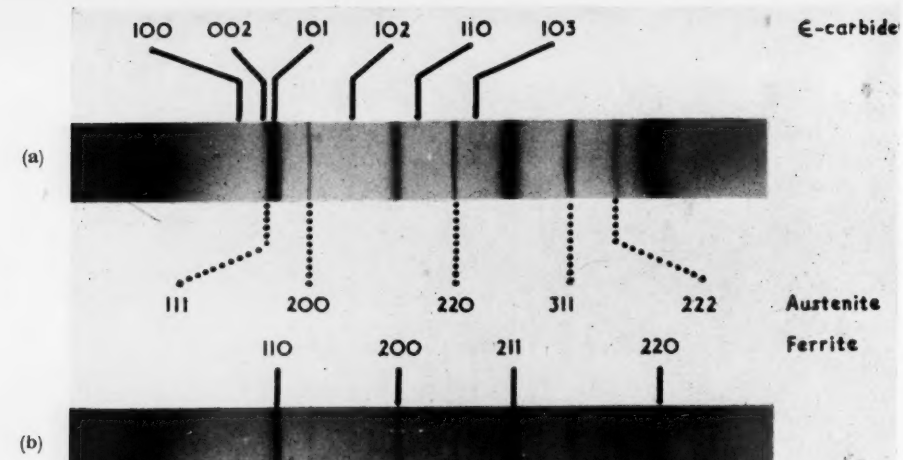
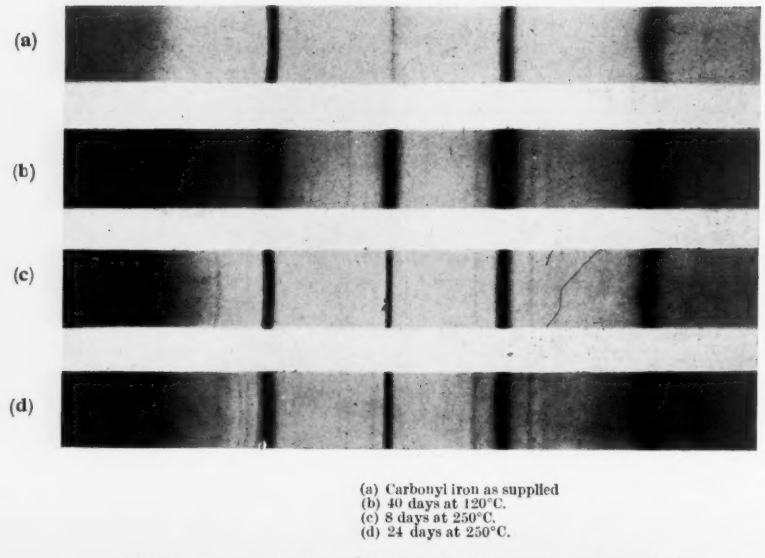


(a) 7½ days at 120°C.
(b) 4 days at 160°C.
(c) 12 days at 160°C.
(d) 6 days at 250°C.
(e) 21 days at 350°C.

Fig. 2—X-ray powder spectra of martensitic steel (specimen *B*) tempered at 120°, 160°, 250°, and 350°C.



(a) Carbonyl iron as supplied
(b) 40 days at 120°C.
(c) 8 days at 250°C.
(d) 24 days at 250°C.

Fig. 3—X-ray powder spectra of heat-treated carbonyl iron

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(i) It is hardly less ferromagnetic than martensite
(ii) It does not give a cementite Curie point
(iii) The observed contraction in volume is only about one-quarter of the value calculated from the relative densities of martensite, ferrite, and cementite.[4]

The third stage is considered to be the formation and growth of cementite from the transition phase.

The tetragonal structure of martensite is preferred on theoretical grounds,[5] except at small carbon concentrations, so that the loss of tetragonality of martensite must seem to be accompanied by some kind of carbide precipitation. Dijkstra[6] found no evidence, from his internal friction measurements, of any precipitated phase other than cementite when supersaturated solid solutions of carbon in α-iron were tempered, but the carbon concentrations (about 0·02 wt.-%) were very small compared with those of martensitic steels.

Arbusov and Kurdjumov[7] presented evidence purporting to show the existence of an unknown carbide when martensite (formed from quenched single crystals of austenite) was tempered at 130–300° C. Five very weak reflections, observed on X-ray photographs of the tempered material, occurred at Bragg angles of 18°, 28°, 31°, 44°, and 52·5°, for FeKα radiation. In some cases one or two of these diffuse reflections were absent, and only the last four may be regarded as definite. Although the reflections occurred at Bragg angles near those of certain cementite lines (*see* Table II), Arbusov and Kurdjumov considered they could not be due to cementite, because :

(i) The intensities were not the same as those expected for cementite, *i.e.*, the observed reflections were not the strongest in the normal cementite diffraction pattern
(ii) The orientation of the crystals was not the same as the known orientation (with respect to parent austenite and martensite single crystals) of cementite formed at high temperatures.

Kurdjumov and Lyssak[8] consider that the tempering of high-carbon martensite at 125–150° C. produces not ferrite but a martensite of smaller axial ratio, with a carbon concentration of about 0·4–0·5 wt.-%. The axial ratio and carbon content decrease with increasing tempering temperature, but slight tetragonality is maintained up to about 300° C. The carbon precipitated is assumed to be the unknown iron carbide postulated by Arbusov and Kurdjumov. Above 300° C., Kurdjumov and Lyssak found gradually increasing amounts of cementite. However, Isaitchev[9] (*see* Kurdjumov[10]) found that the cementite produced at 300–400° C. has slightly different unit-cell dimensions from those of cementite formed at higher temperatures, and shows differences in the intensities of reflections. All such differences are said to vanish at about 650° C.

Recent electron-microscope studies of tempered steels[11] provide additional evidence that carbon is rejected from martensitic solid solution as an unstable transition carbide different from cementite.

Possible Structure of the Transitional Phase

The only work which gives a direct clue to the structure of the transition carbide is that of Heidenreich, Sturkey, and Woods,[12, 13] who, as a result of their electron-diffraction investigations, report that a martensitic steel (0·9% of C, 0·15% of Si, 0·0056 wt.-% of N) tempered at 200° C. contains a fine dispersion of hexagonal Fe_3N, or some phase isomorphous with Fe_3N, without any trace of cementite. This 'Fe_3N' is transformed to cementite at 350° C. and, according to Heidenreich *et al.*, may be the same as Arbusov and Kurdjumov's unknown 'carbide.' Subsequent investigation of the iron–carbon–nitrogen system[14, 15] suggested that the hexagonal 'Fe_3N' was possibly an ε-iron carbonitride. Crafts and Lamont[16] examined extracted residues from plain carbon and alloy steels tempered at various temperatures up to 750° C. : below 475° C., X-ray photographs showed a diffraction pattern which they claim to be that of the transition carbide of Arbusov and Kurdjumov,[7] and which they also identify as the carbide Fe_2C obtained by the reaction of carbon monoxide with ferric oxide (Gluud, von Otto, and Ritter[17]). These conclusions are not in agreement with the very incomplete experimental evidence reported, and are mutually incompatible (*see* p. 29; also Hofer *et al.*[18]). A close-packed hexagonal carbide, probably Fe_2C and prepared by prolonged carburizing of reduced Fischer-Tropsch iron catalysts at temperatures near 200° C., has been characterized by magnetic and X-ray methods, by Hofer, Cohn, and Peebles.[18] This carbide forms the carbon-rich extreme of the isostructural series of ε-iron carbonitrides[14, 15] of composition $Fe(C,N)_{0·3\rightarrow0·5}$, and is not to be confused with iron percarbide,[19, 20] which has a complex structure (*see* Fig. 1*f*). Although Hofer *et al.* consider that both the hexagonal carbide and iron percarbide have the same chemical composition, Jack[20] claims that the carbon content of the latter is less than that of Fe_2C. Above about 300° C. the pure hexagonal carbide decomposes, with or without rejection of carbon, to the complex iron percarbide, which in turn decomposes more slowly to cementite and free carbon. Hofer and Cohn[21] reported recently that both these higher carbides react with iron at temperatures between 260° and 500° C., to give cementite and no free carbon.

In the low-temperature tempering of nitrogen–martensite (Jack[22]), a transition iron–nitrogen phase, α″, is formed by an ordering of the nitrogen atoms with only very small changes in the relative positions of the iron atoms. The possibility of a similar ordering of interstitial carbon atoms in the tempering of carbon-martensite had therefore to be considered.

SCOPE OF PRESENT INVESTIGATION

The work described in this paper was carried out primarily to determine the nature and structure of the intermediate transition phase, the formation and decomposition of which is thought to be associated with the first and third stages of steel tempering. The results provide direct evidence that the loss of tetragonality of martensite during the first stage is caused by the coherent precipitation of a close-packed hexagonal iron carbide, which it is proposed should be named ε-iron carbide because of its structural similarity to the ε-phase of the iron–nitrogen system. During the third stage, the ε-iron carbide transforms to give a fine dispersion of very thin platelets of cementite, which gradually recrystallizes with increas-

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Table I

X-RAY REFLECTIONS FROM THE CLOSE-PACKED HEXAGONAL IRON–CARBIDE TRANSITION PHASE (ϵ-Fe_3C) OF MARTENSITE TEMPERED AT 120° C.

Intensities*	Indices, *hkl*	ϕ_{min}	Interplanar Spacings, kX.					'Fe$_3$N' (Heidenreich *et al.*[12, 13]) $a = 2{\cdot}729$ kX., $c = 4{\cdot}326$ kX.		'Fe$_2$C' (Hofer *et al.*[14]) $a = 2{\cdot}749$ kX., $c = 4{\cdot}340$ kX.	
			Observed After:				Calculated for: $a = 2{\cdot}729$ kX., $c = 4{\cdot}326$ kX.				
			5 days	7½ days	40 days	40 days		*d*	Intensities	*d*	Intensities
m	100	28°	2·36	2·40	2·38	2·37	2·36	...	...	2·38	w
vw	002	61°	2·12	2·15	...	...	2·16	2·18	s	2·16	m
†	101	0	...	...	...	...	2·07	2·09	vs	2·08	vs
ms	102	18°	1·60	1·60	1·60	1·60	1·60	1·61	s	1·60	m
w	110	41°	1·36	1·36	1·37	1·36	1·36	1·38	s	1·37	m
m	103	30°	1·23	1·23	1·23	1·23	1·23	1·23	s	1·24	m

* vw = very weak, w = weak, m = moderate, ms = moderately strong, s = strong, vs = very strong
† Masked by $\gamma_{\{111\}}$ and $\alpha_{\{110\}}$ reflections

ing tempering times or at higher temperatures. Possible mechanisms for the solid phase transitions are discussed, and the proposed structural changes are correlated with the well-known changes in hardness and specific volume of steels during tempering.

Following a suggestion by Mr. H. P. Rooksby, parallel experiments were carried out with carbonyl-iron powders.

EXPERIMENTAL DETAILS

Small rods of pure iron–carbon martensitic steel,* similar to those used by Lipson and Parker[23] for the determination of the structure of martensite, were used. These showed some loss in tetragonality from their original condition, four to five years earlier, and were therefore re-quenched from 1100° C. An X-ray photograph of one specimen is shown in Fig. 1*a*; the tetragonality of the martensite ($c/a = 1{\cdot}059$) and the cell dimensions of the retained austenite indicate a carbon concentration of 1·3 wt.-% (6·2 C atoms per 100 Fe atoms). The rods were sealed in evacuated Pyrex tubes, and were tempered for varying times at temperatures in each of the ranges associated with the three successive stages of steel tempering. Carbonyl-iron powders containing 0·7–1·0 wt.-% of carbon were similarly treated.

X-ray powder photographs were taken at 18 ± 2° C. in a 9-cm. cylindrical camera, using crystal reflected FeKα radiation ($\alpha_1 = 1{\cdot}93208$ kX.; $\alpha_2 = 1{\cdot}93601$ kX.) from a lithium-fluoride monochromator.

RESULTS

The Tempering of Martensitic Steel at 120° C.

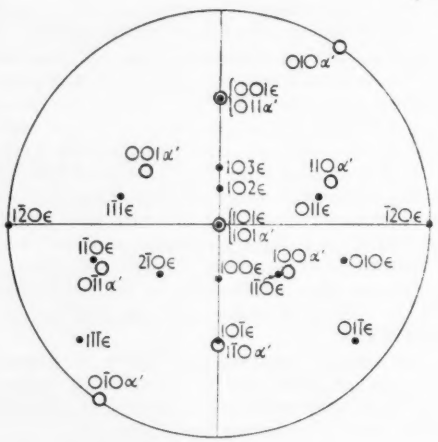
Figures 1*b* and *c* are photographs of a martensitic steel (specimen *A*, *see* Fig. 1*a*) tempered at 120° C. for 5 and 40 days, respectively. No decomposition of retained austenite was apparent, but the martensite pairs of reflections characteristic of the tetragonal structure were replaced by broader ferrite lines, the breadth of which increased with tempering time. In addition, very faint and diffuse lines were observed and are marked on the photographs. These increased in intensity with increasing tempering time. A photograph (Fig. 2*a*) of a thinner rod (specimen *B*), tempered at 120° C. for 7½ days, also gave exactly similar faint reflections. Table I shows that these additional reflections are due to a close-packed hexagonal phase, ϵ-iron carbide. The unit cell dimensions:

$$a = 2{\cdot}72(9)\ \text{kX.};\quad c = 4{\cdot}32(6)\ \text{kX.};\quad c/a = 1{\cdot}58(5)$$

are similar to those given for Heidenreich's 'Fe$_3$N,' and are slightly smaller than those for Hofer's 'FeC$_2$.'

The Structural Mechanism of ϵ-Iron Carbide Formation

All the observed reflections from ϵ-iron carbide were broad and very diffuse bands, the relative intensities of which (*see* Table I) were not the same as those given for Heidenreich's 'Fe$_3$N' or for Hofer's 'Fe$_2$C,' nor were they similar to those given by any usual close-packed hexagonal arrangement of metal atoms. The measurement by photometric methods of the integrated intensities of such weak and diffuse X-ray reflections is impossible. Visual estimation gives only the peak intensity, which, for a three-dimensional crystal, is inversely proportional to the half-peak



$(101)_{\alpha'}$ parallel to $(10\bar{1})_{\epsilon}$
$(011)_{\alpha'}$ parallel to $(001)_{\epsilon}$
$[100]_{\alpha'}$ at an angle of 5° with $[110]_{\epsilon}$

Fig. 4—Stereogram showing the orientation relationships between martensite and ϵ-iron carbide

* Supplied by Dr. A. M. B. Douglas.

width of the reflection (*see* Jones[24]). On a stereographic projection of the structure (Fig. 4), the angular distance between any plane normal (*hkl*) and the (101) plane normal was roughly proportional to the relative weakening of the usual intensity of the (*hkl*) reflection required to give the observed (*hkl*) peak intensity. Any plane that is not parallel to the (101) plane gives rise to a reflection the peak intensity of which is weakened. The weakening, and therefore also the line breadth, are observed to be functions of the angle (ϕ_{min}, Table I) which that plane makes with the (101) plane. Since X-ray line broadening is ascribed either to the smallness of the crystallites or to the presence of non-uniform lattice strains (*see* Wilson[25]), the observed diffraction effects indicate that the transitional iron-carbide crystallites are sufficiently large, or their lattice periodicities are sufficiently perfect, to obey the Laue condition for X-ray reflection only in directions that are approximately normal to the (101) planes. Similar precipitate particles in aged aluminium–silver and in aluminium–magnesium–silicon alloys are referred to by Geisler and Hill[26] as ' stringlets.'

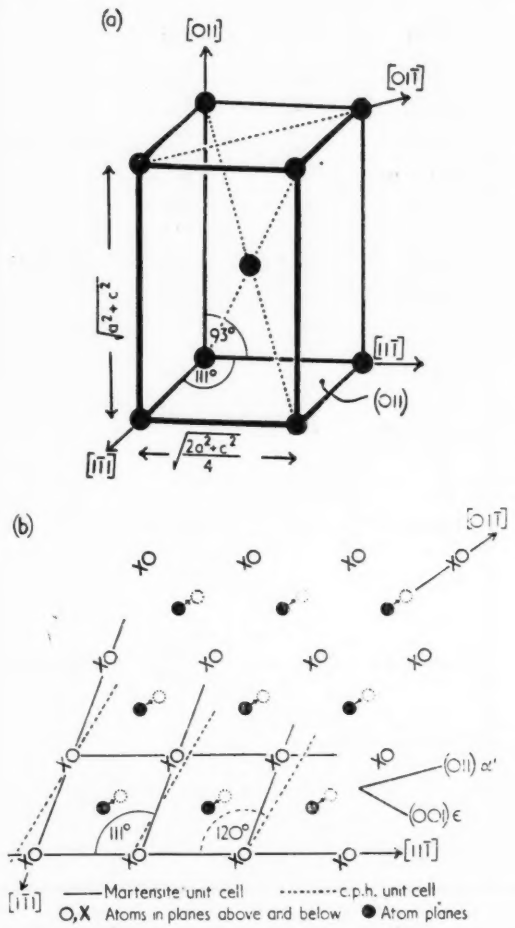


Fig. 5—The structure of martensite : (*a*) Shown as a distorted hexagonal lattice; (*b*) showing the formation of a close-packed hexagonal structure

The interplanar spacings of the (101) planes of the hexagonal carbide (2·07 kX.) are almost identical with those of the (101) planes of tetragonal martensite (2·06 kX.), which in turn are orientated parallel to the (111) shear planes of the parent austenite. It is suggested that, during the formation of ε-iron carbide from martensite, the (101) planes of the former are parallel to and coherent with, *i.e.*, ' fit ' with, the (10$\bar{1}$) lattice planes of the latter. Some simple orientation relationship between the iron atoms of the martensite and the iron atoms of the carbide is probable, and if the relationship is that shown in the stereogram, Fig. 4, where $(101)_{\alpha'}$ is parallel to $(101)_{\epsilon}$ and the angle between $[100]_{\alpha'}$ and $[110]_{\epsilon}$ is 5°, then the $(011)_{\alpha'}$ and $(001)_{\epsilon}$ planes are also parallel. Figure 5 shows how a shear of the martensite lattice, accompanied by small movements in the [01$\bar{1}$] direction of alternate (011) planes of iron atoms, results in the formation of an approximately close-packed hexagonal structure in which the orientation relationships proposed above are maintained.

It is not suggested that the formation of ε-iron carbide from martensite is by a shear mechanism ; indeed, the process is clearly one of nucleation. But the creation of a nucleus which is capable of growth will occur readily when the necessary atomic movements are small. Maximum growth of the ε-carbide crystallites is observed in the direction normal to the (10$\bar{1}$) planes, and it is in this direction that the ' misfit ' of iron atoms is a minimum.

The Tempering of Martensitic Steel at Temperatures from 160° to 350° C.

Figure 1*d* is an X-ray photograph of martensitic steel (specimen *A*) tempered at 250° C. for 12 days. The photographs in Figs. 2*a–e* are of martensitic steels (specimen *B*) tempered at 160° C. for 4 days (Fig. 2*b*) and 12 days (Fig. 2*c*) ; at 250° C. for 6 days (Fig. 2*d*) ; and at 350° C. for 21 days (Fig. 2*e*). Other experiments with intermediate temperatures and times were carried out, but the salient features are evident from the photographs reproduced.

The retained austenite decomposes relatively slowly at 160° C., the decomposition being nearly complete after 12 days ; at 250° C., the same stage is reached in less than 6 days. Reflections due to the hexagonal transition carbide vanish with the disappearance of austenite. The exact range of temperature over which the transitional phase decomposes could not be ascertained, as at the same time a second new diffraction pattern, gradually increasing in strength with increasing time and increasing temperature, was observed. The first definite appearance of these new reflections was after 6 days at 250° C., but they are clearly seen after 12 days at this temperature (Fig. 1*d*), and gradually increase in intensity up to 21 days at 350° C. (Fig. 2*e*). The observed interplanar spacings and intensities are listed in columns 6 and 7 of Table II, and it was noted that the four unidentified reflections observed by Arbusov and Kurdjumov[7] correspond approximately with some of the stronger reflections of this phase. Exact agreement is not to be expected, as the Russian workers used only a

5-cm. dia. single-crystal camera, and located their very weak reflections by reference to the broad diffraction lines of the α- and γ-phases. Moreover, their reflections consisted of diffuse diffraction spots, and it is possible that spots not close to the equatorial region would not be observed, because of the obliquity of incidence of X-rays on non-equatorial positions on a cylindrical film.

At first it was thought that the new diffraction effects were caused, as suggested by Arbusov and Kurdjumov, by a new carbide phase. It was then realized that, in all cases, the positions of the reflec-

Table II

X-RAY REFLECTIONS FROM MARTENSITE TEMPERED AT 250° C. COMPARED WITH THOSE FROM CRYSTALLINE CEMENTITE

1	2	3	4	5	6	7	8	9
Crystalline Cementite					Martensite Tempered at 250° C. for 12 days			Arbusov and Kurdjumov[7]
Indices, *hkl*	F^2p*	Observed Intensities†	Observed Spacings, kX.	$\phi°$	Observed Spacings, kX.	Observed Intensities†	Indices, *hkl*	Observed Spacings, kX.
101	29	...	...	56				
110	4	vw	3·358	90				
002	19			0				
111	20	vw	3·018	63				
020	128	w	2·536	90	2·51	m	020	
112	850	ms	2·371	45				
021	802			69	2·38	m, br	021	
200	845	mw	2·248	90	2·26	m	200	
120	653	mw	2·207	90	2·20	m	120	
121	2638	ms	2·098	72	2·10	w	121	
210	2628	ms	2·058	90	2·06	ms	210	2·06±0·05
022	2599	m	2·018	53	2·04–2·00		($110_{\alpha\text{-Fe}}$)	
103	5069	vs	2·004	28				
211	2204	ms	1·968	73	1·97	w, br	211	
202	92	m	1·862	56				
113	1907			34				
122	2700	ms	1·846	57	1·83	m, br	122	1·88±0·05
212	1200	m	1·756	58	1·76	w, br	212	
220	27	m	1·679	90	1·68	vw	220	
004	370			0				
023	799			42				
221	625	w	1·633	76				
130	1351	m	1·582	90	1·57	s	130	
123	129			45				
131	359	w	1·539	77			131	
213	54	...	...	47	1·53–1·52	vw, br		
222	1009	mw	1·506	63			222	
114	194			27				
301	5	...	...	77				
310	33	...	...	90				
132	21	...	...	65	1·44–1·42		($200_{\alpha\text{-Fe}}$)	
311	386	vw	1·409	78				
024	461	w	1·403	33				
230	1	vw	1·346	90				
204	47			37				
223	90			53				
124	282	vw	1·339	37				
231	6	s	1·326	79	1·34–1·32	m, br	(231)	1·39±0·03
312	2609			67			312	
214	4	...	...	39				
320	4	vw	1·289	90				
133	14			55				
105	240			19				
321	1	...	...	79				
040	5	...	...	90				
232	784	w	1·255	68				
115	279	vw	1·250	22				
303	4			56				
041	7			79				

* The intensity of a powder reflection is given by :

$$I = \text{const.} \times F^2_{hkl} \cdot p \cdot f(\theta) \cdot Ae^{-B\sin^2\theta/\lambda^2},$$

where the symbols have their usual meanings. Values of F^2p show the relative intensity contributions of unresolved reflections in a composite line

† vw = very weak, w = weak, mw = moderately weak, m = moderate, ms = moderately strong, s = strong, v = very strong; br = broad

tions were very similar to those of some of the cementite lines, but that the relative intensities were completely different. Some of the strong cementite reflections were absent, whereas certain weak cementite reflections appeared quite strong in the new pattern. Again, some of the new lines appeared to be broader than others, although at higher Bragg angles all lines were diffuse.

All anomalies were resolved by considering that the precipitated carbide phase has a cementite structure in which the Laue condition for X-ray reflection is fulfilled only in directions parallel to the (001) planes of the lattice, and is relaxed in the [001] direction, *i.e.*, in the direction perpendicular to the (001) planes. Complete relaxation of the Laue condition in one particular direction indicates that

Table II—(*cont.*)

1	2	3	4	5	6	7	8	9
Crystalline Cementite					Martensite Tempered at 250° C. for 12 days			Arbusov and Kurdjumov[7]
Indices, *hkl*	F^2p*	Observed Intensities†	Observed Spacings, kX.	$\phi°$	Observed Spacings, kX.	Observed Intensities†	Indices, *hkl*	Observed Spacings, kX.
140	2628	s	1·221	90	1·22–1·21	vs, br	140	1·22±0·01
313	2977	s	1·212	57			(313)	
322	8	...	...	69				
141	245	vw	1·202	79				
224	223	ms	1·189	45				
025	1132			28				
042	116			69	1·18–1·16		(211$_{\alpha\text{-Fe}}$)	
233	3726	s	1·159	59				
134	173	ms	1·149	47				
125	2618			31				
142	172			70				
400	526	w	1·127	90	1·13–1·12	vs, br	400	
215	1805			33				
330	2462	s	1·124	90			330	
006	1460	m	1·123	0				
323	1			60				
331	560	vw	1·109	80			331	
240	38	s	1·104	90	1·11–1·10	s, br	240	
043	2975			60			(043)	
410	1373	ms	1·102	90			410	
314	947	mw	1·095	49				
241	1	...	...	81				
411	811	mw	1·087	81	1·09	mw, br	411	
143	73	...	...	61				
402	37	...	...	71				
332	368	w	1·066	71				
116	2			19				
234	278	mw	1·052	43				
225	818			39				
242	181			72				
412	414	vw	1·046	72				
420	14	...	...	90				
135	333	vw	1·026	40				
026	12			24				
324	6			52				
421	554	vw	1·020	81	1·02–1·01		(220$_{\alpha\text{-Fe}}$)	
044	47	...	...	53				
333	1	w	1·005	59				
206	390			26				
305	3			42				
126	188	vw	1·001	27				
243	1056	ms	0·9924	64				
150	133			90				
413	5	...	...	64				
144	232	s	0·9854	54				
422	530			73				
216	1191			29				
315	1409	ms	0·9843	43				

* The intensity of a powder reflection is given by :

$$I = \text{const.} \times F^2_{hkl} \cdot p \cdot f(\theta) \cdot Ae^{-B\sin^2\theta/\lambda^2},$$

where the symbols have their usual meanings. Values of F^2p show the relative intensity contributions of unresolved reflections in a composite line

† vw = very weak, w = weak, mw = moderately weak, m = moderate, ms = moderately strong, s = strong, v = very strong; br = broad

the diffracting material exists as two-dimensional layers, the plane of each layer being perpendicular to the relaxation direction. Warren[27] has described the X-ray powder diffraction effects to be expected from a two-dimensional layer, and shows that only (*hk*0) reflections occur. For each (*hk*0) reflection there is a continuous distribution of intensity at angles greater than the normal Bragg angle, θ_0, and the maximum intensity is displaced from θ_0 towards larger angles by an amount :

$$\Delta(\sin\theta) = \frac{0{\cdot}16\,\lambda}{L}, \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where L is the average dimension of the crystallite in the plane of the layer. For $L = 250$ kX. and $\theta_0 = 45°$, and for FeKα radiation, the displacement of the peak line intensity is only 0·1°, corresponding to an apparent decrease of 0·0024 kX. in interplanar spacing. The distribution of intensity in a powder reflection given by randomly orientated two-dimensional arrays has also been plotted by Jones.[24] His results indicate that, for platelets of about 40 unit cells in diameter, the intensity of the 'tail' of the (*kh*0) reflection is small compared with the peak intensity, and where a number of such reflections are recorded simultaneously, as in the present case, the overlapping 'tails' will appear as enhanced background blackening.

Values of F^2p (column 2, Table II) for crystalline cementite are calculated for FeKα radiation from the structure proposed by Lipson and Petch,[28] and show the relative intensity contributions of unresolved reflections in a composite line.

Values of ϕ are also listed (column 5, Table II), where ϕ is the angle between a cementite lattice plane (*hkl*) and the (001) cementite plane. The observed intensities (column 7, Table II) for the new diffraction pattern must again be regarded as peak intensities. Only those reflections for which l is small are observed, and the strongest reflections are those for which l is zero. For $\phi = 90°$, *e.g.*, for the (020), (200), (120), (210), (220), (130), (140), (400), (330), (240), and (410) reflections, the intensity is greatly enhanced in relation to the intensity of the same reflection from three-dimensional cementite, while for the (004) and (006) reflections, where $\phi = 0$, the intensity is negligible. For intermediate values of ϕ, the observed intensity appears to equal the normal cementite intensity multiplied by a function of ϕ. In addition, (*hk*0) reflections are less diffuse than (*hkl*) reflections.

X-ray photographs of crystalline cementite and of iron percarbide are shown in Figs. 1*e* and *f*, for comparison.

The observed effects are fully explained if the iron-carbide precipitate consists of a dispersion of very thin platelets of cementite, the plane of each platelet being parallel to the (001) lattice plane of the cementite structure. Most of the platelets must be only one or two unit cells in thickness, and so give a typical two-dimensional powder diffraction pattern. In the specimen examined there must also be an appreciable proportion of rather thicker platelets, because these give rise to a weaker, superposed, three-dimensional pattern with the Laue condition partially relaxed in the [001] direction.

The positions of the diffuse reflections from the cementite platelets could not be measured as accurately as those of the sharp, fully crystalline cementite reflections ; but the apparent reduction in interplanar spacing of the former, due to the displacement of two-dimensional peak intensities towards larger Bragg angles, does not exceed about 0·01 kX. (*cf.* respective (130), (140), and (410) reflections). Thus, according to equation (1), the mean diameter of the cementite platelets cannot be much less than 20 unit cells, and is probably of the order of 50 unit cells.

A marked feature in the photographs reproduced in Figs. 1 and 2 is that, whereas the formation from martensite of the close-packed hexagonal transition carbide is accompanied by an increase in the breadth of the ferrite lines, the subsequent decomposition of the hexagonal phase by the precipitation of cementite platelets is accompanied by a sharpening of these same ferrite reflections. The sharpening of the ferrite reflections during the third stage of steel tempering has been noted by many investigators, some of whom have attributed it to recrystallization of the α-iron matrix. Wheeler and Jaswon[29] have shown that the broadness of the initial martensite reflections is largely the result of strain, and it follows that the increased broadening observed during the first stage of tempering is caused by an even greater lattice strain resulting from precipitation of the finely dispersed ε-iron carbide. During the third stage of tempering, this transition phase is transformed to very thin cementite platelets—again finely dispersed, and probably orientated regularly with respect to the hexagonal phase. The gradual growth and recrystallization of the cementite with increasing tempering times, or at higher temperatures, must be accompanied by a reduction in lattice strain ; consequently, gradual sharpening of the ferrite reflections is to be expected.

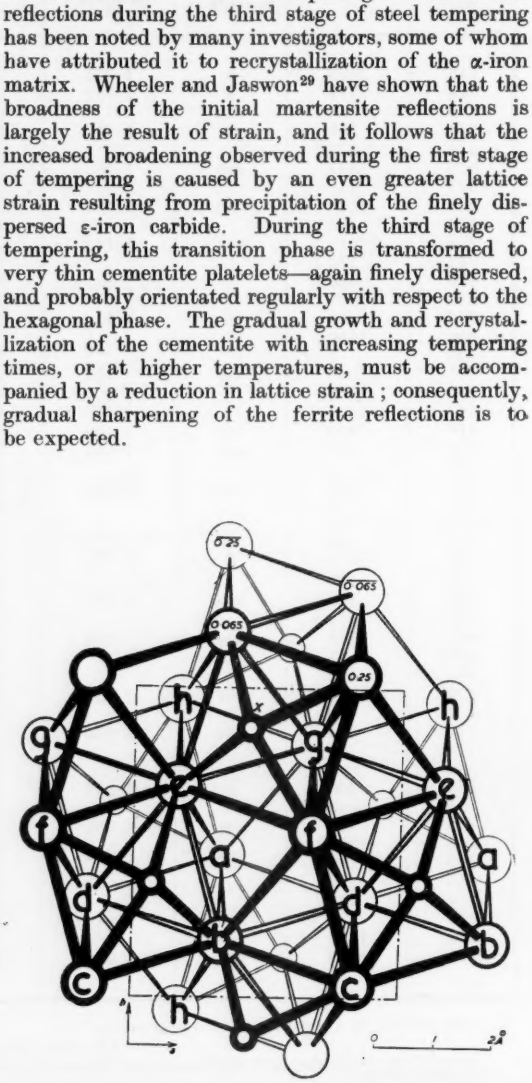


Fig. 6—The cementite structure (Lipson and Petch[28]).

The Structural Mechanism of Cementite Formation

It has been shown that the transitional close-packed hexagonal ε-carbide is obtained from martensite by very simple movements of the iron atoms. If the hexagonal phase is a true transitional structure, it follows that the cementite structure is possibly also simply related to it.

Figure 6 is an exact reproduction of the structure of cementite as given by Lipson and Petch,[28] except that eight of the twelve iron atoms contained in the unit cell are distinguished by the letters *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h*. These atoms are redrawn in Fig. 7 in exactly their same relative positions, and it is evident that the arrangement of these eight iron atoms is almost exactly that of a close-packed hexagonal structure. Atoms *a*, *b*, *c*, and *d* are approximately close-packed in one plane, and atoms *e*, *f*, *g*, and *h* are similarly close-packed in a parallel plane, which is displaced from planes above and below it in the same way as the *ABAB*... sequence of planes characteristic of a close-packed hexagonal lattice. These ' close-packed ' planes are shown in Fig. 8*a*, which is a projection of the cementite unit cell in the [100] direction. The four additional atoms *p*, *q*, *r*, and *s* in the cell are slightly displaced from the ' close-packed ' planes, which are shown by the projection to be parallel to, and to have the same interplanar spacing as, the (022) planes of cementite. A second projection of the cementite structure, this time in a direction perpendicular to the (022) planes, is given in Fig. 8*b*. Three successive planes of iron atoms, A_1BA_2, are distinguished in the diagram by representing the atoms of different planes by differently outlined circles. For perfect hexagonal close packing, the atoms of plane A_1 should lie directly above the atoms of plane A_2. The major atomic movements required for the transformation of the cementite structure to a close-packed hexagonal structure of dimensions $a = 2{\cdot}7$–$2{\cdot}8$ kX. and $c = 4{\cdot}1$ kX. are shown in Figs. 8*a* and *b* by arrows. The largest movements are those of the four atoms *p*, *q*, *r*, and *s*, but even these are less than one-half of the smallest iron–iron distance. The hypothetical dimensions given above for the close-packed hexagonal arrangement are calculated on the assumption that the volume of structure per iron atom is the same as that in cementite. ' Complex ' interstitial alloy structures are always more dense than ' normal ' ones (*see* Hägg[30]), so that the close-packed hexagonal arrangement of iron atoms of the transitional phase from which the cementite structure is derived might be expected to have unit-cell dimensions slightly larger than those calculated directly from the proposed

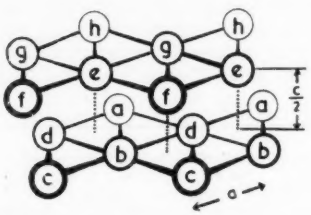


Fig. 7—Cementite as an approximate close-packed hexagonal structure

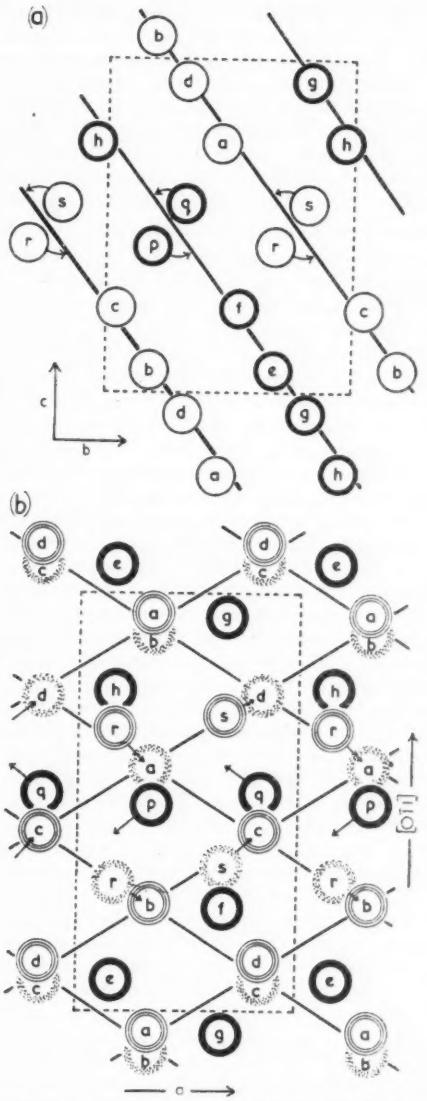


Fig. 8—Projection of cementite: (*a*) in the [100] direction; (*b*) in a direction normal to the (022) planes

atomic movements. The observed unit-cell dimensions, $a = 2{\cdot}73$ kX. and $c = 4{\cdot}33$ kX., of the ε-iron carbide are in agreement with this possible transition mechanism.

Comparison of the Tempering Mechanisms for Carbon–Martensite and Nitrogen–Martensite

The decompositions of carbon–martensite and nitrogen–martensite are analagous in that a transition phase is produced in both systems. The first product of the tempering of nitrogen–martensite is α″-iron nitride,[22] which is formed as an orientated precipitate coherent with the matrix in two principal lattice directions ; ε-iron carbide also occurs as a coherent precipitate. The structures of both transition phases (α″ or ε) are intermediate between those of the

initial phases (nitrogen– or carbon–martensites) and those of the final products (Fe_4N or cementite, respectively). The movements of iron atoms necessary for their formation and for their subsequent transformation are relatively small, so that nucleation and precipitation of Fe_4N from nitrogen–martensite, and of cementite from carbon–martensite, can probably occur more readily *via* the appropriate transition phase than by a single-stage nucleation process.

The Heat-Treatment of Carbonyl Iron

Carbonyl-iron powder prepared by thermal decomposition of iron carbonyl at about 140° C. contains up to about 1 wt.-% of carbon, and gives an X-ray powder photograph (Fig. 3*a*) showing very broad ferrite lines similar to those obtained just before the third stage of martensite tempering. Photographs of specimens heat-treated for 40 days at 120° C., for 8 days at 250° C., and for 24 days at 250° C., are shown respectively in Figs. 3*b–d*. At these temperatures the ferrite reflections gradually sharpen, and the changes that occur are exactly the same as those observed during the third stage of martensite tempering. Very thin platelets of cementite are precipitated, and give rise to X-ray reflections of which those from (*hk*0) planes are strong and sharp whilst those from planes (*hkl*), where *l* is large, are broad and diffuse, or are absent. As in the first formation of cementite from martensite, the plane of the cementite platelet is parallel to the (001) crystal plane. A few faint extra reflections were identified as the strongest powder lines of Fe_3O_4, so that a small amount of oxygen was presumably present in the original carbonyl iron. The transformations in the powder occur much more rapidly than those in the steel rods. Normal crystalline cementite was obtained at 350° C., and the presence of ε-Fe_3C was not directly observed even at the lowest annealing temperature. In the original carbonyl iron, the carbon must be combined with the iron in a state different from that of the cementite into which it eventually transforms. The very low temperature of formation precludes its existence as tetragonal martensite, and (as has been mentioned previously) the existence of cubic martensite is most improbable. The broadness of the ferrite reflections is too great to be ascribed solely to the size of the crystallites, and must be due, as in the case of tempered martensite, to lattice strain. The carbon of carbonyl iron is present, therefore, as a precipitate, possibly coherent and too finely dispersed to give any characteristic X-ray diffraction effects. It is probable that this carbide is ε-iron carbide, but in any case the condition of the carbonyl iron is similar to that reached at the end of the second stage of steel tempering.

DISCUSSION

The results obtained in the present work show that the transformation of martensite to cementite occurs in two stages. The initial body-centred tetragonal martensite structure transforms very easily to a hexagonal close-packed iron carbide which is isostructural with ε-iron nitride. Nuclei of the cementite structure are then obtained by only small distortions of the transition structure. Although no large movements of the iron atoms are necessary, the formation of cementite must be accompanied by diffusion of carbon atoms. If this takes place only during the first stage of the process, the transitional close-packed iron carbide must have a composition represented by Fe_3C.

It is reasonable to infer that there exists a close-packed hexagonal ε-iron–carbon phase, with a range of composition approximately from Fe_3C to Fe_2C, which forms the carbon-rich extreme of the ε-iron carbonitrides, in the same way as the ε-iron–nitrogen phase forms the nitrogen-rich opposite extreme of the same series of ternary alloys.[15] Although it is possible that Hofer's carbide is ε-Fe_2C, chemical analysis shows only that the carbon content is not less than 29 at.-%. The unit-cell volume of the first product of martensite decomposition is about 1·8% less than that of Hofer's carbide, and if the reduction in cell volume with decreasing interstitial-atom concentration is similar to that in the ε-iron–nitrogen phase, then the carbon concentration of the tempered steel transition carbide is about 3 at.-% less than Hofer's supposed Fe_2C. From the known variation of cell dimensions with increasing carbon/nitrogen ratio in the ε-carbonitrides,[15] the carbon concentration of the transition carbide is calculated as 25–30 at.-%. The available evidence, though indirect, indicates that the composition of the ε-iron carbide found in tempered steels is nearer Fe_3C than Fe_2C.

The successive processes in martensite decomposition :

(i) martensite ⟶ ε-iron carbide
(ii) ε-iron carbide ⟶ cementite

represent the so-called first and third stages, respectively, of steel tempering.

Dimensional Changes in Tempered Martensitic Steels

The explanation given for the changes that occur on tempering martensitic steel is based on direct experimental evidence, but is similar to that deduced, from dimensional changes, by Fletcher and Cohen,[4] who postulated the existence of a transitional carbide. In the present work, the specific volumes of all the iron–carbon phases, including the transitional ε-Fe_3C, are known from X-ray measurements, and therefore the dimensional changes calculated for the various stages of steel tempering may be compared with the changes observed on tempering a commercial steel.

Table III

CALCULATED AND OBSERVED DIMENSIONAL CHANGES FOR TRANSITIONS IN CARBON STEELS

Transition		Changes in Specific Volume, %	
Initial Material	Final Product	Calculated (Present Work), 1·3 wt.-% of C	Observed (Fletcher and Cohen[4]), 1·26 wt.-% of C
Martensite	Cementite + α-Fe	−2·2	−2·1
Martensite	ε-Fe_3C + α-Fe	−0·5	−0·6
ε-Fe_3C + α-Fe	Cementite + α-Fe	−1·7	−1·6
Austenite	ε-Fe_3C + α-Fe	+3·4	+3·2
Austenite	Cementite + α-Fe	+1·7	+1·7

As shown in Table III, the values calculated for various transitions in a 1·3 wt.-% C steel are in excellent agreement with those found by Fletcher and Cohen for a steel containing 1·26 wt.-% of C.

Hardness Changes in Tempered Martensitic Steels

All hardening processes in alloys provide 'slip interference' in its widest sense, but in age-hardening three fairly distinct processes have been recognized (Geisler[31]). These are :

(i) Solid solution hardening
(ii) Coherency hardening
(iii) Dispersion hardening.

Coherency hardening is the term used to distinguish the properties of a two-phase system in the unique and unstable transition state at which the phases are strained into precise atomic registry, or coherency, in planes parallel to the interface. The particles of the coherently precipitated phase are usually very small and, since they are strained to 'fit' with the atomic sites of the matrix, are orientated with respect to the matrix, usually producing one-dimensional or two-dimensional X-ray diffraction effects. As the particle size of the precipitate increases, the coherency stresses at the interfaces also increase, and when these exceed a critical value the particle breaks away from the matrix and may recrystallize as a dispersed phase. The coherent precipitate, with its surrounding field of strained matrix, offers greater resistance to slip than an incoherent dispersed precipitate. The softening reactions tending to work in opposition to the three hardening processes are :

(i) Depletion of solid solution
(ii) Loss of coherence, *i.e.*, recrystallization
(iii) Coalescence.

The changes in hardness of martensitic steels on tempering may be interpreted by such ideas.

Apart from the one-dimensional X-ray effects given by ε-iron carbide, and its orientation with the matrix, its formation is accompanied by pronounced strain-broadening of the ferrite X-ray reflections. Indeed, the line breadths exceed those of the original martensite pattern and increase with increasing precipitation. The evidence that the first stage of martensite tempering is similar to other age-hardening systems is therefore complete, and the increase in hardness which accompanies the formation of ε-iron carbide as a coherent transitional phase is to be expected.

The second and third stages of tempering overlap. Even if the retained austenite decomposes directly to cementite without (as seems more probable[1, 4]) the intermediate formation of ε-carbide, the first-formed cementite platelets have all the characteristics of a very finely dispersed precipitate, and only retarded softening is likely. The same is true at the beginning of the third stage, but with increasing tempering times, or with increasing temperatures, the recrystallization and coalescence of the cementite platelets are accompanied by reduction in lattice strain and a marked softening.

Structural Changes in Steel due to Cold Working

Lattice distortion of cementite involving interplanar spacing changes of about 0·75% has been observed by Wilson[32] in cold-worked high-carbon spheroidized steels. Anomalous intensities of X-ray reflections accompany the apparent distortion. These phenomena are reminiscent of those found during the early part of the third steel-tempering stage, but are quantitatively dissimilar to the latter. The structural changes in the cementite are not expected to be the same in the two cases where the internal stress conditions must be quite different; nevertheless, both investigations indicate that the cementite lattice is susceptible to stress and orientation influences.

The proposed mechanisms by which martensite decomposes to ε-iron carbide, and by which ε-iron carbide then transforms to cementite, are such that the transitions might be expected to be modified by externally applied stresses. The possible existence of ε-iron carbide in cold-worked steels, and the possible acceleration of the tempering process in stressed materials, are subjects for future inquiry.

Electron-Microscope Studies of Tempered Steels

The results of recent electron-microscope investigations[11] are in agreement with, and offer considerable support for, the mechanism of steel tempering proposed in the present paper.

Acknowledgments

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Low-Temperature Fractures in Tempered Alloy Steels

By A. R. Entwisle, B.A.

SYNOPSIS

Low-alloy steels susceptible to temper-embrittlement may show fracture at low temperatures with either a cleavage or an intergranular fracture, depending on the heat-treatment. The cleavage type of failure is shown to be related to the original martensite structure produced on quenching. Under certain conditions both types of failure can occur in the same fracture. Plain-carbon steels similarly heat-treated show cleavage but not intergranular fracture.

As part of an investigation of temper-brittleness, a study has been made of fractures of plain-carbon and low-alloy steels at low temperatures, the latter steels being in various states of temper-embrittlement. Previously, McClean and Northcott[1] examined low-temperature types of fracture in tempered steels in the ' tough ' and brittle condition, and noted the ' leaf-like ' structure of the fracture of the tough steel. The present work is a more detailed examination of the fractures obtained under experimental conditions that produce brittle fracture.

EXPERIMENTAL TECHNIQUE

The low-alloy steel used for most of the investigation was type En 23, as follows :

Chemical Composition, %

C	0·41	As	0·085
Si	0·70	Cr	0·66
Mn	0·43	Ni	3·01
S	0·0295	Mo	0·05
P	0·024		

Specimens of this material (0·45-in. rounds) were oil-quenched from 1250° C., tempered for 1 hr. at 640° C., and subsequently embrittled at 525° C. The high quenching temperature was used so as to develop a large austenite grain size to facilitate metallographic observations. The actual size established was rather mixed, but was in the range 0–3 A.S.T.M. After being notched, the specimens, which were Izod impact test pieces, were fractured at — 180° C., and the fractures were then examined at × 40 and × 400 magnifications.

MICROSCOPIC EXAMINATION

Examinations of the non-embrittled material showed that the fractures were almost completely of the cleavage type, with a very small number of intergranular surfaces. At low magnifications, the fractures were characterized by the sudden changes in direction of fracture at the grain boundaries, and by the austenite grains retaining their individuality in the fracture (*see* Fig. 1). The actual cleavage facets were of the characteristic feathery shapes reported by McLean and Northcott (*see* Fig. 2).

Many areas were observed with structures having many facets in the same plane, similar to that shown in Fig. 3. These facets were considerably larger than the ferrite grain size, which was about 0·8 μ. The similarity between the fracture structure and the microstructure of the specimen seemed to indicate that the 'feathery shapes' corresponded in some way to the martensite plates before fracture. Figure 4 shows the microstructure. (It is shown after embrittlement so that the austenite grain size can be determined.) These areas had fractured in the same plane, indicating that all the ferrite grains over quite large

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Fig. 1

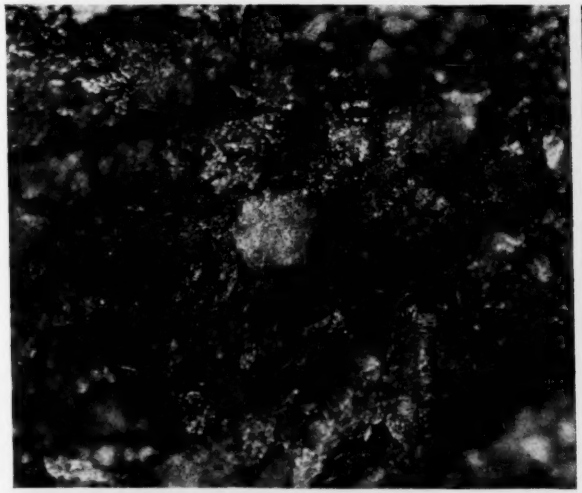

Fig. 2

Fig. 3

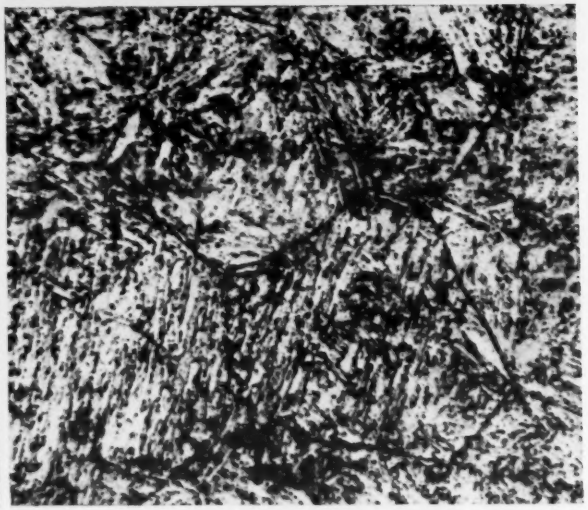

Fig. 4

Fig. 1—Low Temperature fracture of ' tough ' Ni-Cr steel × 72 (Dark field illumination)

Fig. 2—Same fracture as in Fig. 1 × 420 (Vertical illumination)

Fig. 3—Same fracture as in Fig. 1 × 420

Fig. 4—Microstructure of ' tough ' steel after embrittlement × 420

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(a) Before fracture (b) After fracture

Fig. 5—Microstructure of section of embrittled Ni–Cr steel

Fig. 6—Back reflection photograph using CoKα radiation

regions had approximately the same orientation. These regions would seem to correspond with the areas of uniform orientation of the martensite before fracture. Any one austenite grain is thought to transform to a limited number of these regions of uniform martensite orientation.

These ideas were confirmed by using an X-ray back-reflection technique on a polished, etched specimen (*see* Appendix). The X-ray work showed that the ferrite grains were assembled in aggregates of about 60 μ dia. in which the ferrite grain orientations were substantially the same. The actual misalignments are of the order of 3°. As the mean equivalent austenite grain diameter was about 100 μ, these results indicate that any one austenite grain transforms to about eight orientations of martensite, and not to a random distribution of the 24 orientations as might be expected from the Kurdjumov-Sachs relationship.

The microstructure and appearance of the fracture can therefore be correlated. The tempered martensite of plain-carbon steels shows a similar type of fracture. For a very small austenite grain size (A.S.T.M. 8), the fracture studies indicate that the martensite transformation is even more restricted, as each grain appears to form only two or three facets.

EXAMINATION OF FRACTURED IMPACT SPECIMENS

The fracture of temper-embrittled alloy steels has long been thought to be intergranular with respect to the prior austenite grains.[2] This was further demonstrated in the following way :

An Izod specimen (square section) of a severely embrittled sample of the En 23 steel was made in two halves. The plane of separation was along the longest axis of the specimen perpendicular to the plane of the notch and parallel to the direction of impact. The two surfaces at the dividing plane were polished, and etched with an ethereal solution of picric acid and CTAB[1] to reveal the austenite grain size. The microstructure near the notch was then photographed. The two specimen halves were bolted tightly together, and the composite specimen was fractured at — 180° C. In this way deformation at the polished surfaces was restricted. After fracture, the microstructure at the fractured edge was photographed and compared with the photographs taken previously. Plastic deformation had been almost eliminated, and it was possible to trace the course of the fracture across the specimen. It was found to be substantially intergranular with respect to the prior austenite grains. Figure 5*a* shows a typical area before fracture, and Fig. 5*b* the same area after fracture. Portions of the edge that are slightly out of focus indicate regions of plastic deformation. The free surface is not favourable for propagating brittle fracture, and where grain boundaries are unfavourably orientated with respect to the advancing crack, some deformation takes place before fracture.

Examination of the surface of the fracture rather than the section shows the characteristic gently curved facets associated with intergranular failure. The surfaces are rough and contain many small particles which were thought by Nutting[3] to be carbides. When examined in polarized light, the larger particles (at the grain edges) are found to have the same optical properties as the larger grain-boundary carbides in the microsection (only the larger particles are suitable for observation). The grain-boundary carbides are larger than the average particle size, which is consistent with the observation that the particles on the fractured surface are larger than average.

The effect of progressive embrittlement at 525° C. on the fracture at — 180° C. was studied. After 15 min. at 525° C. the fracture was found to be about 50% intergranular; after 45 min., about 80% intergranular; and after about 2 hr. it was almost exclusively intergranular. Since the 15-min. treatment would only lead to a change in transition temperature of the order of 10° C. it is evident that the fracture changes from one type to the other quite rapidly; after a quite small change in transition temperature subsequent changes must result from the increasing ease of intergranular fracture and not from increasing proportions of intergranular failure. This is being studied further, but it appears that the low-temperature brittle fracture of an alloy steel might be used as a sensitive test for detecting small amounts of temper-embrittlement. If the intergranular fracture is taken as the criterion of temper-embrittlement, then the test can be used to determine whether or not changes of transition temperature in steels are associated with temper-brittleness. At present, all adverse changes in transition temperature in low-alloy steels are usually ascribed to temper-brittleness, but this may not be true.

With very fine-grained steels (A.S.T.M. 8–9), it is more difficult to discriminate between the two types of fracture, because all the phenomena are on a smaller scale, and it is not easy to compensate for this by increasing the magnification.

In the mixed fractures (*i.e.*, cleavage plus intergranular) there is a tendency for the intergranular facets to occur more frequently near the notch, and for the cleavage fracture to predominate at points away from the notch. The type of failure at any given place is probably controlled by the orientation of the grain boundary, the stress conditions, and the non-uniformity of the precipitation, but the effect of each is not known. The surface-active etching reagents (CTAB etc.) give non-uniform etching effects, and uniform precipitation plays an important part as no cleavage facets appear in severely embrittled specimens.

The information obtained from these experiments was used to determine, from a study of the fracture of plain-carbon steels (tempered martensite), whether they were susceptible to temper-brittleness, as had been suggested by Jaffe and Buffum.[4]

Specimens of a steel (B.S. En 8) containing 0·4% of C, and 0·65% of Mn were used. They were quenched in brine from 1000° C., tempered for 1 hr. at 630° C., and water-quenched. Some were then 'embrittled' by heating at 480° C. for 24 hr. After breaking notched samples in liquid oxygen, the fractures were examined. In both sets of specimens the fracture was predominantly cleavage, but the specimen treated at 480° C. did contain a small amount (not more than 5%) of intergranular facets. This refutes the hypo-

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thesis of Jaffe and Buffum, that plain-carbon steels are highly embrittled, even when quenched after tempering above 600° C., and suggests that the high transition temperatures of plain-carbon steels are not a result of temper-embrittlement.

DISCUSSION

As far as is known, a prior austenite grain boundary in tempered martensite is characterized by :

(i) Large carbide particles

(ii) Change in ferrite orientation with no simple relationship.

There are other possibilities, *e.g.*, segregation of alloying elements (which occurs in burning and overheating) and inclusions which will tend to be located in the grain boundaries. There will also be some form of precipitate located there when the material is embrittled. These characteristics are the normal grain-boundary features.

The experimental evidence shows that a tough steel when fractured in liquid nitrogen has a special type of cleavage fracture. This is shown to be associated with the structure of the ferrite (which is derived from the martensite). The ferrite grains (about 1 μ) are in groups of about 50 μ dia. (for this particular coarse austenite grain size) in which they all have the same orientation. There is microscopic evidence that the boundaries of these regions are characterized by carbides that are larger than average, and are thus similar to the austenite grain boundaries. This indicates that the effective ferrite grain size is 50 μ rather than 1 μ (*i.e.*, A.S.T.M. grain size 6).

As the austenite grain size decreases, so the size of the orientated regions decreases. Thus, for A.S.T.M. grain size 9, the ferrite regions are size 10. It may be the variation in size of these ferrite areas, together with the change in particle-size distribution of the carbides, that explain the effect of austenite grain size on the properties of tempered steels.

The intergranular fracture is shown to be a sensitive criterion for temper-embrittlement. The change from cleavage to intergranular fracture is shown to be continuous, but rapid. The mixed fractures are important, since they demonstrate that discontinuous embrittlement is sufficient to raise the transition temperature. This emphasizes that the transition temperature for any given specimen represents an average value for the whole specimen, and that fracture is easier in some regions than in others.

The intergranular fracture of temper-brittle steels is interesting in two respects :

(i) Because of the peculiar nature of the grain boundaries involved

(ii) Because of the localized precipitation effects.

The limited form of the precipitation may show that it is initially due to some segregation taking place while the steel is austenitic. This can cause localized precipitation on subsequent quenching and tempering.

Acknowledgments

The author thanks Professor G. Wesley Austin for his advice and encouragement, and Mr. G. C. Smith of the Department of Metallurgy, Cambridge University, for much helpful discussion. The steel used was kindly supplied by Mr. H. Bull, of Brown-Bayley's Steelworks, Ltd. The work was financially supported by B.I.S.R.A.

APPENDIX

X-Ray Method

By P. B. Hirsch, M.A., Ph.D.

A back-reflection photograph was taken with an X-ray beam of about 1 mm. dia. (CoKα radiation). The photograph consists of arcs along Debye-Scherrer rings (Fig. 6). Each arc corresponds to a region of strong preferred orientation in the material. The numbers of arcs (N_1, N_0) on the Debye-Scherrer rings on two photographs of different exposures (T_1, T_0) were counted and the mean volume V of material contributing to one arc could be determined from the relation :

$$\frac{N_1 - N_0}{A \log_{10}(T_1/T_0)} = \frac{2 \cdot 3p \cos\theta}{2\mu(1 - \sec 2\theta)} \cdot \frac{1}{V} \cdot (d\theta + \Delta)$$

where A is the area of the beam at the specimen (measured photographically) ; p is the multiplicity factor for the reflecting planes ; μ is the absorption coefficient ; θ is the Bragg angle ; $d\theta$ is the divergence of the X-ray beam (measured photographically) ; Δ is the range of angles over which the region can reflect. The quantity Δ was determined from the lengths of the arcs along the ring using the relation

$$\sin\tfrac{1}{2}\Delta = \cos\theta.\sin\tfrac{1}{2}\gamma$$

where γ is the angle subtended by the arc at the centre of the diffraction ring.

The mean diameter of the regions of preferred orientation was found to be about 60 μ, while the range of mis-orientations was about 3°. It is of interest to note that as the diffraction rings were quite sharp the size of the ferrite particles (forming aggregates of diameter about 60 μ) was expected to be 1 μ, in agreement with the metallographic evidence.

Further details about the method of counting spots and its application to the study of substructure in materials have been given elsewhere.[5, 6, 7]

Dr. Hirsch is at the Crystallographic Laboratory, Cavendish Laboratory, Cambridge.

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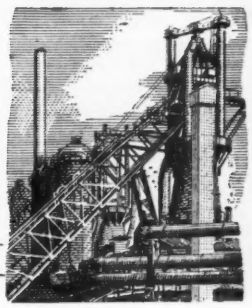

Experiences with the Escher Metallic Recuperator on High-Temperature Furnaces

By H. Escher

SYNOPSIS

Operating experience obtained at the Port Kembla Steelworks of Australian Iron and Steel, Ltd., on furnaces equipped with Escher recuperators, is described. Performance figures are given for a 10-in. mill billet-heating furnace, equipped with recuperators, which has been in operation for some time. A general description, including data on furnace operation, is given of the billet-heating furnace for the new Rod-and-Strip Mill which commenced operation in October, 1949.

Heating characteristics of coke-oven gas and blast-furnace gas as fuel for firing are compared. It is shown that thicker stock can be more satisfactorily heated in a single zone by using blast-furnace gas firing rather than coke-oven gas. A proposed design for a single-zone blast-furnace-gas-fired furnace is discussed.

Introduction

SOME operating results for furnaces equipped with the Escher recuperator[1] at the works of Australian Iron and Steel, Ltd., Port Kembla, N.S.W., have already been published.[2, 3] Results have also been reported on trials carried out on an experimental unit by the Research and Development Department of The United Steel Companies, Ltd., Rotherham.[4]

The present paper deals with further operating experience and data obtained at the Port Kembla Steelworks, and new developments are discussed, including reference to glass tank installations, which are of particular interest because of the high temperatures (2300–2550° F.) of the flue gases entering the recuperators, and also their high dust content.

The development of the Escher metallic recuperator was begun in 1941–42, when the coke-oven-gas supply at the Port Kembla Steelworks was insufficient to meet the rapidly increasing demands of the steel-melting shop. By converting a large number of soaking pits and a billet-heating furnace to blast-furnace-gas firing, substantial quantities of coke-oven gas became available. Firing with blast-furnace gas involves the use of fairly large recuperators operating at a much higher temperature than is required with coke-oven-gas firing. The recuperators of the new billet-heating furnace for the Rod-and-Strip Mill at Port Kembla return about 17,500,000 B.Th.U./hr. to the heating cycle, which represents about 50% of the total heat transferred to the stock under average operating conditions. Blast-furnace-gas firing has proved simple and safe, and provides excellent heating with small-scale losses.

CONSTRUCTION AND OPERATION

The Escher recuperator is well suited for preheating blast-furnace gas. It is of all-welded construction, consisting essentially of a large-diameter tube through which the flue gases flow, with a second tube surrounding the inner one and forming an annulus through which the gas to be heated moves at high velocities. Circular inlet and outlet boxes make it possible to obtain a uniform distribution of flow and to avoid corners that are not properly swept by the gas stream. The volume of enclosed gas in the recuperator can be kept to a minimum, which is of particular importance for quick and effective purging. Usually, it is not necessary to use steam for purging, except when there are several units connected to a common header. The comparatively smooth, vertical surface of the annulus reduces the possibility of dust deposition, and no cleaning of the gas-swept heating surfaces has been required on any unit, although some have been in service for nine years. The total capacity of blast-furnace-gas recuperators installed or under construction at Port Kembla is more than 3,000,000 cu. ft./hr. of blast-furnace gas, and a considerable number of units are being built in England.

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The largest inner tube used so far has a dia. of 4 ft., and the greatest length of some units under construction is 90 ft. The recuperators illustrated in Figs. 1 and 2 are typical of large units operating with counter flow and with inlet flue-gas temperatures of up to 2000–2100° F.

The rate of heat transfer by convection on the flue-gas side is progressively increased towards the cold zone, by whirlers, to compensate for the drop in heat transfer by gas radiation. Some indication of the improvement in total heat transfer obtained using whirlers is given in the report[3] of trials of this recuperator. On a pack-furnace in a sheet mill, a whirler located at one-third of the length of the recuperator from the cold-air box gave an air preheat temperature of 647° F. (342° C.), compared with 500° F. (296° C.) obtained without whirlers. With the arrangement shown in Fig. 1, the normal frictional losses are small, and a pressure of approx. $\frac{3}{4}$ in. W.G. would be available for the whirlers.

The range of annulus widths is from 0·2 to 3·0 in., the small gaps being used on tubes of small diameter, and the large gaps on long recuperators of large diameter. The kinetic energy of the heated gas at the outlet end of the annulus is considerable and is converted into pressure by a diffusor section, which assists in reducing the total pressure drop through the recuperators. Accurate spacing in the gap is maintained by longitudinal fins welded to the inner tube, and under certain conditions the width of the annulus may be graded. As well as adding to the heat-transfer surface, these fins strengthen the structure.

The inner tube transfers heat by radiation to the outer tube, with particular effect at high metal temperatures. Steel containing 25% of Cr and 20% of Ni has a very high coefficient of emissivity. In the counter-flow recuperators, heat transfer by radiation from the inner to the outer tube is poor at the cold end, and a larger number of fins may be welded there, to the inner shell of the annulus, to compensate for this.

Heat-resisting steels have a low thermal conductivity, but the heat passes through a comparatively thin metal wall only, so that the temperature gradients are small, even with very high rates of heat transfer. The thermal conductivity of low-carbon steel at 400° F. is about $2\frac{1}{2}$ times greater than that of chrome steels at 1000–1300° F., and fins are particularly effective in the low-temperature zone.

Other features that make this recuperator particularly suitable for high temperatures are as follows:

(i) The heat radiation from the inlet and outlet flues is spread over a large portion of the recuperator surface, and there is no direct impingement of the flue gases against any part of the heating surface

(ii) Gas radiation from the enclosed gas to the circular surface is uniformly graded

(iii) The flue gases are so guided through the tube that heat transfer by convection is evenly graded

(iv) At very high temperatures of the metal, internal radiation assists in equalizing metal temperatures.

These features should make reliable service possible with preheats of about 1500° F., and there are considered to be reasonably good prospects for developing a recuperative open-hearth furnace with this recuperator. Ideas on design have already been published.[3]

Use is made of the thermal expansion of the heating surface to limit the metal temperatures or to distribute the heat output between a number of recuperators. On the Rod-and-Strip-Mill furnace recuperator at Port Kembla the normal expansion of the heating surface is 4–5 in., but allowance has been made for a total expansion of 9 in. An asbestos-packed joint is provided to allow for expansion between the recuperator and the connecting furnace flue. Flexible connection between the recuperator hot box and the burner-supply pipes is provided by a water-sealed joint or by a floating pipe, as shown in Fig. 1.

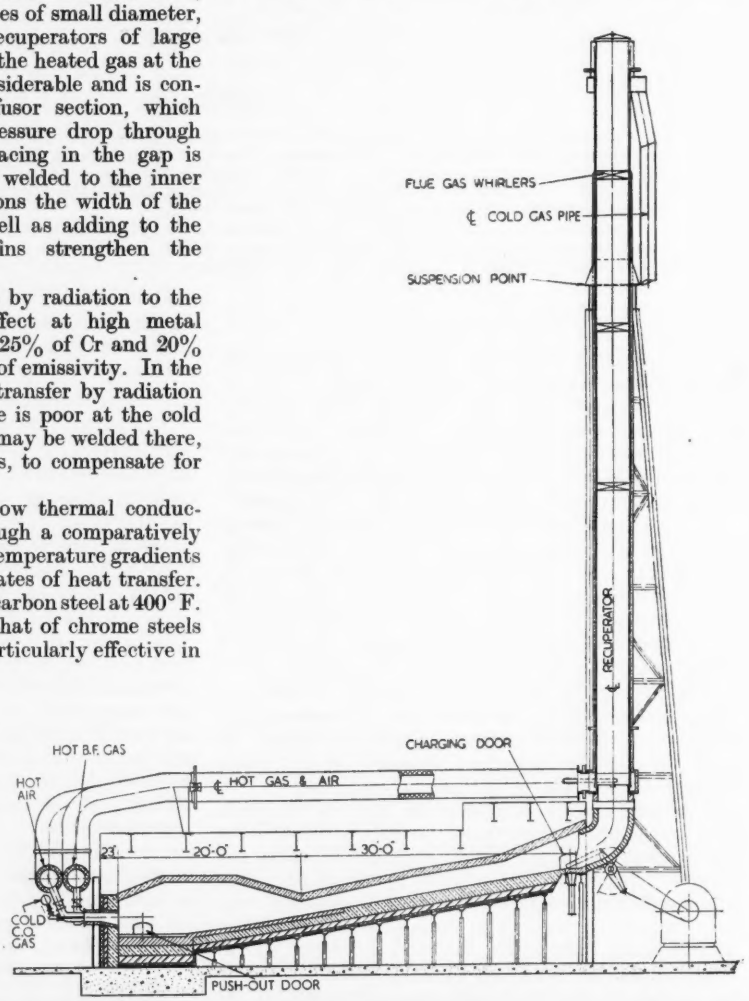

Fig. 1—Large-capacity furnace fired with blast-furnace gas

The pipe is provided with two metallic flexible joints and swivel pins which take the load at one end, and at the recuperator end the weight is transferred centrally to the recuperator.

With flue-gas temperatures above 2000–2100° F., either the entire recuperator or a part of the unit is usually arranged so that the flue gases and the air or gas to be heated flow in parallel. Part of the outer tube at the cold-air (flue-gas inlet) end is left without insulation, so that sufficient heat is radiated to prevent excessive temperatures being reached at very low air flows or during interruption of the air supply. The effectiveness of this protection against overheating has been well proved on an installation that is subject to frequent interruptions of the air supply owing to electrical blackouts.

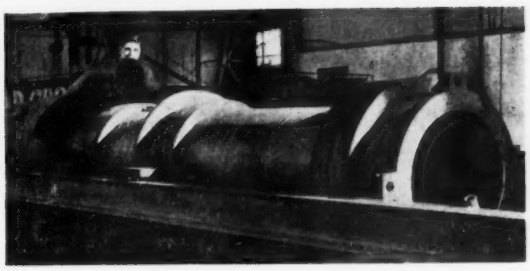

Fig. 3—View of horizontal recuperator for soaking pit

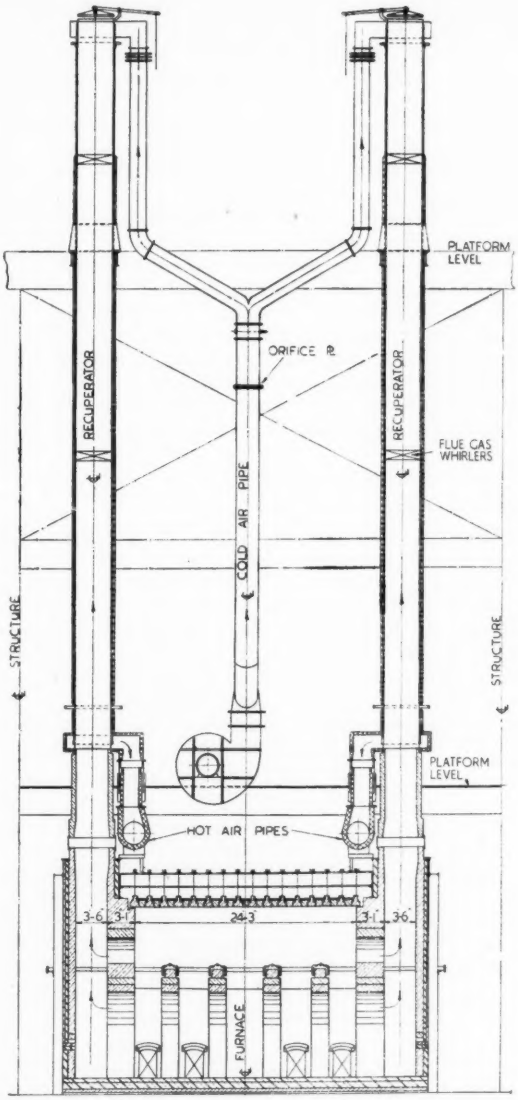

Fig. 2—Recuperator installation for 100-ton/hr. slab-heating furnaces

The original soaking-pit recuperators at Port Kembla were designed, constructed, and installed in less than six months during 1942 ; since then, important improvements in design have been developed. Heat-resisting steel was not readily available in Australia at the time, and the first unit installed on a soaking pit was made entirely of mild steel, with internal brick-lining in the flue. This lining was 4½ in. thick in the hot zone and 2 in. thick in the cold zone : thinner linings that were used on later units caused some trouble. The refractory lining reduces the rate of heat transfer, and new developments have aimed at a completely unlined construction, except where corrosive attack of the metal is to be expected. One of the horizontal brick-lined units installed on a soaking pit in 1942 has been replaced by the unit without internal brick-lining, shown in Fig. 3. This unit is set up in a horizontal position. It is 15 ft. long, with an internal dia. of 2 ft. and is kept in tension by springs, which reduce the tension as the temperature of the metal increases. The heating surface is only 25% of that of the original brick-lined unit, but the air preheat temperature is higher and reaches 1300° F. The soaking-pit installations made at Port Kembla during 1941–43 also have vertical mild-steel recuperators with internal refractory lining, for pre-heating the blast-furnace gas. These recuperators are supported at the base, and the heating surface is under compression : this is a weakness in the design, and several failures have occurred owing to deformation of the lower part of the recuperator when the units have become overheated.

All vertical units built after the initial installation in 1943 are suspended units, which can support temperatures well above the normal working range without damage.

RECUPERATORS FOR GLASS-MELTING FURNACES

Several glass tanks using the Escher recuperator have been built in Australia and England. One installed in Sydney has produced up to 16 tons of glass per day, and has been in service for 2½ years. The melting end at the glass surface is 14 ft. long × 8 ft. 3 in. wide (115·5 sq. ft.), and the semicircular working end has a surface area of 45 sq. ft. Figure 4 shows a cross-section of the furnace, the waste-gas flues, and the recuperators. The furnace is fired

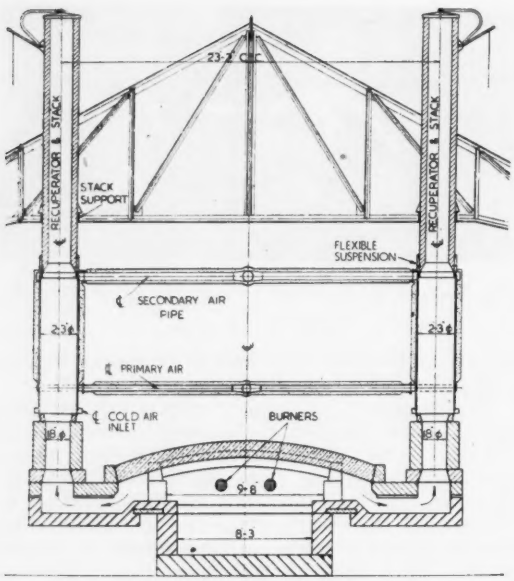

Fig. 4—Cross-section of glass-melting furnace and recuperators

with gas-works' tar of the following composition:

Constituent	Amount Present, %
Carbon	88·0
Hydrogen	6·8
Oxygen	3·1
Nitrogen	0·7
Sulphur	0·6
Ash	0·1
Water	0·5

Over a period of five days, the fuel consumption was 8,600,000 B.Th.U. per ton of glass. The average daily production was 15·8 tons of glass, after the furnace had been in service for 60 weeks. The temperature at the melting end was 2500° F. The combustion air fan supplies the primary air used for atomization, as well as the secondary air. Figure 5 shows a cross-section of one of the two burners. These burners have an internal insulating-refractory lining, and the primary air pipe, atomizer vanes, and burner tips are made of heat-resisting 25% Cr–20% Ni steel. The secondary air pressure at the burner when firing 32 gal./hr. of tar is about 2 in. W.G., and the primary air for atomizing is at a pressure of about 15–25 in. W.G. Primary air was initially preheated in the recuperator, and was then extracted from an intermediate belt. However, as the regulating valve for the air supply is upstream from the recuperator, the air pressure in the extraction belt was at times too low for satisfactory atomization, and a direct air supply from the fan is now used. The burners give a very good, well-guided flame, and all metal parts are at present in perfect condition. The roof of the furnace is still in good condition after 2½ years of service, and it is not certain whether it will need renewing at the next shutdown, which is scheduled for the end of 1951, after three years of service.

The furnace has two waste-gas outlets, and, to keep the length of the waste-gas flues short, one recuperator has been installed on each side of the furnace. These recuperators are made of 25% Cr–20% Ni steel (except for the inlet box and the box for primary air, which are of mild steel); the internal diameter of each is 2 ft. 3 in., and the length is 8 ft. 3 in. They are suspended at the top by means of flexible steel straps, which allow unrestrained radial expansion of the hot-air belt. The cold air enters the recuperator at the bottom, flowing parallel to the flue gases, and is metered by an orifice on the suction side of the fan; from the reading on the flow meter an easy correlation between air and fuel may be made. There is no air leakage in the system. No protective devices are installed, except for an electrical contact which operates a signal when the expansion of the recuperators exceeds a certain value. The Sydney electricity supply has been frequently interrupted during the last two years, because the capacity of the power stations is insufficient. Interruptions of ½–1 hr. have occurred almost daily, and during these periods the air supply to the recuperators is stopped. In spite of these severe operating conditions, no maintenance work on the recuperators has been necessary. A problem in this particular installation has been the accumulation of dust in the brick-lined flue above the recuperator, which can only be cleaned from the top of the stacks.

The average air preheat temperature obtained is only 900° F., with a peak value of 1000° F. At the next opportunity, it is proposed to increase the diameter of the inlet flue from 18 in. to the full recuperator diameter, and to promote some turbulence in the gas stream, so as to raise the average air preheat temperature to above 1000° F. Units installed on other glass tanks operate with air preheats of 1000–1100° F.

CONTINUOUS STEEL-HEATING FURNACES

General Features

The two billet-heating furnaces on the 10-in. mill and the new Rod-and-Strip Mill at Port Kembla Works are equipped with Escher recuperators for preheating air and blast-furnace gas. The furnace serving the 10-in. mill has been described previously.[2] Over an operating period of seven years, the heating surfaces on the air and blast-furnace-gas sides have required no cleaning; the accumulation of dirt in the hot blast-furnace-gas boxes of the recuperators had to be removed about every 18 months, through

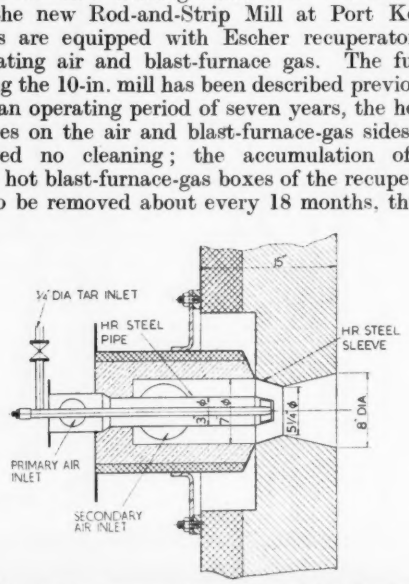

Fig. 5—Tar burner for glass-melting furnace

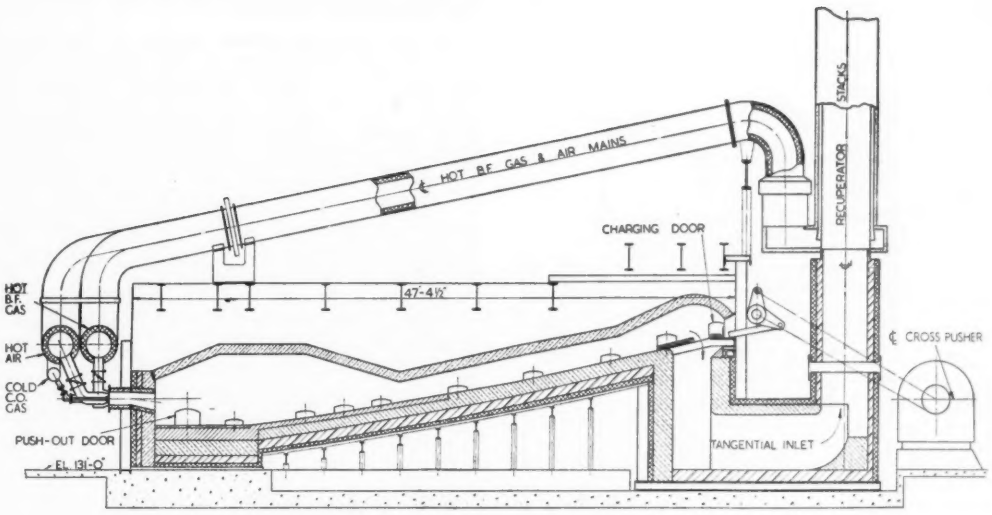

Fig. 6—Section of billet-heating furnace

hand-holes provided in the hot-gas boxes. A small section of the heating surface on the flue-gas side, near the top, has been cleaned once. Some corrosion has taken place in a number of expansion joints in the blast-furnace-gas supply pipes, and in the top box of the blast-furnace-gas recuperators. The blast-furnace gas is cleaned in Theisen disintegrators with salt water, and some of this is entrained in the gas. There has been no corrosion in the air recuperator.

Some corrosion has also occurred in the bottom plate of the hot box. This plate is made of light mild steel, and acts as a diaphragm to compensate for the differential expansion between the inner and outer shells of the recuperator. An improved design has been adopted in the recuperators of the new billet-heating furnace for the Rod-and-Strip Mill. The new design incorporates a solid hot box of rigid construction, and also a separate expansion joint in the outer shell above the box, to accommodate the differential expansion between the two tubes.

The preheats obtained on air and gas vary between 600° and 1000° F. The units have demonstrated their ability to withstand very high temperatures, and on several occasions preheats of 1200° F. have been obtained, with peak values up to 1400° F. Inspection of the heating surfaces does not reveal any deterioration of the metals or of the welds, and the performance and efficiency have remained constant over the period.

Recent performance figures for the 10-in. mill billet-heating furnace, over a period of three weeks and using fuels of low and high calorific values, are as follows :

	1st Week	2nd Week	3rd Week
Amount of steel heated (eighteen 8-hr. shifts), tons/week	2993	5153	2859
Gross calorific value of mixed gases, B.Th.U./cu. ft.	113·0	135·3	342
Fuel consumption : blast-furnace gas, cu. ft.	42,300,000	53,600,000	4,800,000
coke-oven gas, cu. ft.	2,400,000	6,000,000	6,800,000
Gross heat consumption, B.Th.U./ton	1,690,000	1,570,000	1,390,000
Approx. efficiency (including warming-up fuel), %	46·5	50·2	56·5

The fuel consumption figures include fuels used during mill stoppages and for week-end warming-up. The average billet temperature was 2300° F. The billet-heating furnace for the new Rod-and-Strip Mill commenced operation in October, 1949. This mill requires a wide range of furnace output, from 8–10 tons/hr. for light strip to more than 55 tons/hr. for heavy skelp. The furnace, which has a single firing zone, gives very satisfactory heating using straight blast-furnace gas or mixed gas. The maximum output on blast-furnace-gas firing is limited to about 42 tons/hr. ; above this rate, addition of coke-oven gas becomes necessary. An average output of 55 tons/hr. has been maintained over periods of 3–4 hr., the output being limited by the capacity of the rolling mill.

The furnace[2] has an internal length of 43 ft. 9 in., and a width of 32 ft. 1½ in., giving a total area of approx. 1400 sq. ft. The maximum loading of the heating surface, in terms of area covered by billets, is 105 lb./sq. ft. hr. Figure 6 shows a cross-section of the furnace and the outlet flues to the recuperator, and Fig. 7 shows details of the burner arrangement. The centre line of the push-out door (Fig. 7) has been brought to within 2 ft. 6 in. of the burner mouth, as compared with 5 ft. in the 10-in. mill furnace, and this has increased the exposed surface of the billets by 7% without altering the external dimensions of the furnace. The number of burners has also been reduced to 12, compared with 13 in the 10-in. mill furnace. This has made it possible to build larger pillars between the burner tunnels, resulting in a stronger burner wall. When coke-oven gas is used, it is usually mixed with the blast-furnace

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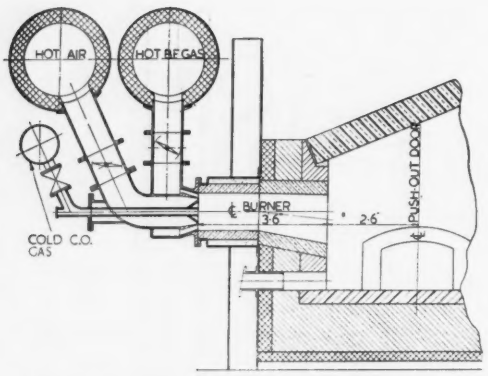


Fig. 7—Gas burner for billet-heating furnace

gas upstream from the recuperators. A central pipe is provided in the burner, so that cold coke-oven gas can be fired straight.

A high degree of spin in the flame, and general turbulence, is obtained, because of the closely pitched blades in the air annulus at the burner tip. The air pressure is 4·8 in. W.G. in the burner header for a flow of 530,000 cu. ft./hr. The high degree of spin in the flame improves heat transfer by convection to the steel and brickwork, which is important in furnaces fired with blast-furnace gas.

On the 10-in. mill furnace the burner noise was objectionable at certain ratings, but on the new furnace the noise level over the entire operating range, and for various fuel mixtures, is very low. The atmosphere in the combustion chamber is remarkably clear. After 20 months of service, the roof is in perfect condition and has only a slight uniform glaze. The furnace roof, side walls, and bottom are well insulated throughout : patching-up of the hearth is carried out through openings at the bottom of the burner wall (*see* Fig. 7). The hearth consists of 2½ in. of chrome, 9 in. of magnesite, 15 in. of firebrick, 7½ in. of insulating refractory, 4½ in. of diatomaceous earth bricks, and 3 in. of common bricks. Underneath these layers, the concrete pad is well ventilated by air channels.

At the charging end of the furnace, the flue gases pass downwards to the flue through a 2 ft. 4 in. gap in the billets, which are supported by water-cooled skids. With blast-furnace-gas firing, the temperature of the flue gases leaving the furnace is 1500–1900° F., according to the rate of firing. At these temperatures, the heat transferred to the skids is appreciable. On the 10-in. mill furnace the heat loss was approximately 3,500,000 B.Th.U./hr., whereas on the new furnace it has been reduced to about 1,800,000–2,500,000 B.Th.U./hr. by decreasing the size of the skids. The drop in temperature of the flue gases, caused by the cooling effect of the skids, is 80–100° F., over a wide range of loads. With coke-oven-gas firing, the temperature of the flue gases leaving the furnace is about 1100° F., and the heat loss from the water-cooled skids is much smaller ; if blast-furnace gas were used, the elimination of the water-cooled skids would provide many advantages.

The Recuperative System

The recuperative system consists of four recuperators arranged in line, two on the outside for the air and two on the inside for the gas. Figure 8 is a general view of the recuperators above the roof line of the furnace building. The 30-in. dia. blast-furnace-gas main approaches the recuperators at a high level, and incorporates a water seal. The automatic gear for controlling the air-to-fuel ratio, the flow, and the pressure, is similar to that on the 10-in. mill furnace previously described.[2] The recuperators are suspended from the main platform (*see* Fig. 8), which is 57 ft. above ground level. The air recuperators have an internal diameter of 3 ft. 9 in., and the gas recuperators a diameter of 4 ft. No dampers are provided between the furnace and recuperators, and there is also no by-pass flue. The lid-type dampers used on top of the recuperators in both furnaces not only give tight shut-off but are easy to move, and have not required any attention since they were installed.

Performance figures for the air recuperators when firing 510,000 cu. ft./hr. of blast-furnace gas and 42,000 cu. ft./hr. of coke-oven gas, are as follows :

Air flow through recuperators, cu. ft./hr.	530,000
Pressure drop on air side, in. W.G.	13·0
Inlet temperature of flue gases (average), ° F.	1730
Air preheat temperature (average), ° F.	930
Approx. waste-gas temperature, ° F.	960
Total heat transfer to air, B.Th.U./hr.	8,700,000
Heat-transfer rate (across surface on flue-gas side), B.Th.U./sq. ft. hr.	5530

The corresponding performance figures for the two blast-furnace gas recuperators are :

Gas flow through recuperators (510,000 cu. ft./hr. of blast-furnace gas + 42,000 cu. ft./hr. of coke-oven gas), cu. ft./hr.	552,000
Pressure drop through recuperator, in. W.G.	5·5

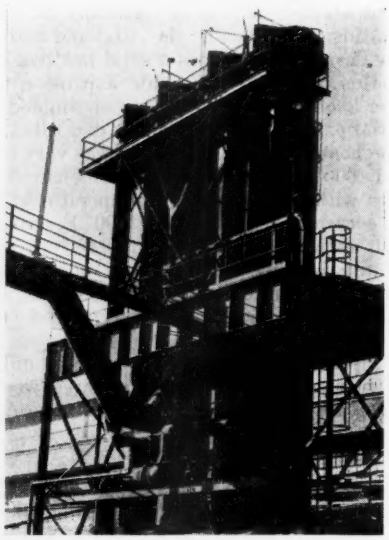


Fig. 8—General view of recuperators on billet-heating furnace

Inlet temperature of flue gases (average), ° F.	1730
Gas preheat temperature (average), ° F.	855
Total heat transferred to gas, B.Th.U./hr.	8,700,000
Heat-transfer rate (across surface exposed to flue gases), B.Th.U./sq. ft. hr.	5200

The oxygen content of the flue gases was 0·4–0·8%. The higher heat-transfer rate for the air recuperators is attributable to the higher velocities used in the annular gap. Using coke-oven-gas firing, the temperature of the flue gases leaving the recuperators is in the range 500–600° F.

The flue gases are automatically distributed between the four recuperators by utilizing the expansion of the recuperators ; Fig. 9 illustrates the arrangement of the proportioning gear. Bracket *A* is attached to the bottom section of the recuperator, and the expansion movement of the stack is transmitted through a connecting rod to a lever *L*, which pivots on a fixed fulcrum *F*. If No. 2 recuperator receives less flue gases than No. 1 recuperator, point *A* will move upwards, because of reduced stack expansion. This will force pulley *P* downwards, and the damper on No. 2 recuperator will open. If the furnace pressure changes because of this adjustment, the power cylinder will move all dampers together as required. For simplicity, only two recuperators are shown in Fig. 9, but on the Rod-and-Strip-Mill furnace all four recuperators are connected together.

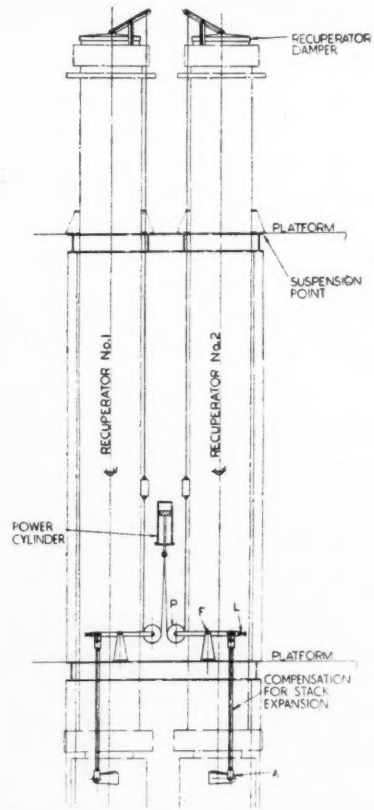
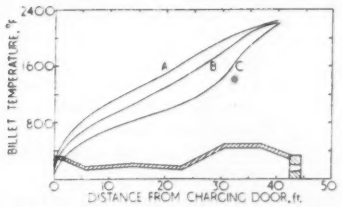


Fig. 9—Gear for the automatic control of flue-gas distribution through the recuperators by thermal expansion



A. 3-in. billets; 45·0 tons/hr. blast-furnace-gas firing
B. 2-in. billets; 24·2 tons/hr. blast-furnace-gas firing
C. 2½-in. billets; 35·0 tons/hr. coke-oven-gas firing

Fig. 10—Billet temperature—furnace location curves for coke-oven-gas and blast-furnace-gas firing

Each recuperator is equipped with a direct-reading expansion gauge, which indicates the total expansion of the suspended section of the recuperator. The temperature of the inlet flue gases to the recuperators is not mechanically controlled.

Furnace Operation

Data for the operation of the furnace at high output are as follows :

Amount of steel heated in 8-hr. shift, tons	413·6
Average heating rate, tons/hr.	51·6
Total blast-furnace gas consumption, cu. ft.	3,960,000
Average blast-furnace-gas flow, cu. ft./hr.	487,000
Total coke-oven gas consumption, cu. ft.	300,000
Average coke-oven-gas flow, cu. ft./hr.	37,500
Calorific value of mixed gases, B.Th.U./cu. ft.	123
Heat consumption, B.Th.U./ton	1,270,000
Steel temperature (approx.), ° F.	2250
Approximate efficiency, %	60

Performance data under average operating conditions, using straight blast-furnace gas, are as follows :

Amount of steel heated, tons/week	2817
Calorific value of mixed gases, B.Th.U./cu. ft.	93
Fuel consumption (blast-furnace gas), cu. ft.	44,200,000
Fuel consumption (coke-oven gas for lighting up), cu. ft.	200,000
Gross heat consumption, B.Th.U./ton	1,470,000
Steel temperature (approx.), ° F.	2250
Approximate efficiency,* %	52

HEATING CHARACTERISTICS OF COKE-OVEN AND BLAST-FURNACE GASES

The average fuel consumption of the new furnace, compared with that of the 10-in. mill furnace (*see* figures for the first week's working, on p. 43), is about 15% less for similar rolling rates. As the Rod-and-Strip Mill furnace at Port Kembla can be fired with either straight blast-furnace gas or coke-oven gas, it is possible to compare the heating characteristics of the two fuels. Figure 10 shows the temperature of the steel as it moves down the furnace, for coke-oven-gas and blast-furnace-gas firing. With blast-furnace-gas firing, the temperature of the flue gases at the furnace exit is in the range 1500–1900° F. ; for coke-oven-gas firing, it is only 900–1100° F. Consequently, the steel-temperature curve for blast-furnace-gas firing is steep at the charging end and flat in the high-

*Figure includes fuel consumed in warming-up

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temperature zone, a condition which approaches the ideal requirements for well-soaked billets. It is evident that thicker stock can be more satisfactorily heated in a single zone with blast-furnace-gas firing than with coke-oven-gas firing. Fast heating at the charging end is particularly desirable for thick stock, because the thermal conductivity of mild steel is much greater at low temperatures.

Although with blast-furnace-gas firing the steel remains at elevated temperatures longer than it does with coke-oven-gas firing, the scale losses are not increased ; tests carried out on the 10-in. mill furnace[4] showed that scale losses with blast-furnace-gas firing were appreciably lower.

Because of the uniform temperature distribution and the elimination of high-temperature peaks in the firing zone, little maintenance of the furnace brickwork is required. Another important characteristic of blast-furnace-gas firing is the ease of operation, and it is not necessary to adjust the fuel input during short mill stoppages. With a high output, using coke-oven gas and high-temperature air preheats, fuel has to be cut off almost instantaneously during a mill stoppage, because of the danger of overheating the steel.

It is important that a furnace feeding a large mill should be reliable ; the availability of the present furnace over a period of 20 months has been 99·6%, the only breakdown being caused by the failure of the wall supporting the skids.

PROPOSED NEW DESIGNS

The Rod-and-Strip Mill furnace has demonstrated that it is possible to obtain excellent heating, from the lowest output rates of about 8–10 tons/hr. to the highest rate of 55 tons/hr., with this single-zone furnace. Figure 1 shows a proposed single-zone furnace fired with blast-furnace gas, suitable for an output range of 10–70 tons/hr. The principal features of this furnace are :

(i) The withdrawal of the flue gases from the furnace through openings in the back wall above the billets, to give minimum pressure drop

(ii) The substitution of short, easily replaceable skids for the water-cooled ones.

The elimination of the water-cooled skids will result in a rise of about 100° F. in the temperature of the flue gas at its entry into the recuperators, so that a higher preheat of air and gas is obtained, giving increased furnace output. The smaller pressure drop in the flue-gas circuit will allow the maximum use of available draught, to improve heat transfer by convection to the recuperators. The elimination of water cooling also results in substantial saving in capital and operating costs. Improved pusher operation can be obtained by greatly reducing the stroke of the pusher, since no gap in the billets for the passage of flue gases need be provided.

Interpolating the data obtained on the Rod-and-Strip Mill furnace, the temperature of the exit flue gas from the furnace, at maximum output, would be in the range 1950–2050° F., and the air and gas would be preheated to about 1100° F.

The inside walls of the furnace are 50 ft. long, and the area covered by steel is about 1350 sq. ft., giving a heating-surface loading rate of 115 lb./sq. ft./hr., which is only slightly above the rate obtained with the Rod-and-Strip Mill furnace.

When all the space above and adjacent to the furnace is serviced by overhead travelling cranes, it is not possible to suspend the recuperators vertically. In an installation on a slab-heating furnace fired with coke-oven gas, in the U.S.A., the recuperators have been placed in a tunnel under the slab yard.

Figure 2 shows the arrangement of recuperators for two slab-heating furnaces, each of 100 tons/hr. capacity, under construction at Port Kembla. The recuperators are located directly above the outlet flues, thus greatly simplifying the construction of the furnace foundations. Each furnace has four 4-ft. dia. recuperators. Two recuperators (one on each side of the furnace) supply air to the top firing-zone burners, and two supply the bottom firing-zone burners ; the soaking-zone burners are supplied with cold air by a separate fan. With this arrangement, the air is metered on the cold side of the recuperators for each zone, giving accurate combustion control.

Acknowledgments

The author wishes to thank the Manager of Australian Iron and Steel, Ltd., Port Kembla, for permission to publish this paper. Thanks are also due to Mr. E. Flynn and Mr. N. Durman, of the Combustion Department, for assistance in obtaining test data, and to Mr. A. A. Taylor, for preparing the diagrams and drawings.

References

1. Australian Iron and Steel, Ltd. : " Recuperator," Australian Patent No. 120,938: Patent applied for : 1944.
2. Australian Iron and Steel, Ltd. : " Improved Recuperator Means for Combustion Furnaces," British Patent No. 590,382 : 1947.
3. H. ESCHER : " Recuperator Means for Combustion Furnaces," U.S. Patent No. 2,538,446 : 1951.
4. H. ESCHER : *Journal of The Iron and Steel Institute*, 1947, vol. 156, pp. 1–27.
5. H. ESCHER : Transactions of the Fuel Economy Conference, The Hague, 1947, vol. III, pp. 1095–1108.
6. T. B. DAVIS, W. ERNEST, and H. KAY : *Journal of The Iron and Steel Institute*, 1951, vol. 167, pp. 66–70.

International Conference on Automatic Control

A Conference on the theory and use of Automatic Control was held at the College of Aeronautics, Cranfield, near Bedford, England, from 16th to 21st July, 1951. Leading scientists and technicians from many countries met to discuss the latest advances in this field, in which Britain has made major contributions.

Sir Ben Lockspeiser, K.C.B., F.R.S., Secretary of the D.S.I.R., opened the Conference and said that it was hoped that the Conference, which had the support and co-operation of the Institution of Electrical Engineers and the Institution of Mechanical Engineers, would advance the development of automatic and normal control systems. The papers read at the conference will be published in October, 1951, by Messrs. Butterworth's Scientific Publications, Ltd., Bell Yard, Temple Bar, London, W.C.2, price 50*s*. The published volume will consist of the papers read at the conference, together with all relevant diagrams and plates, and will include the discussions and questions arising from the papers.

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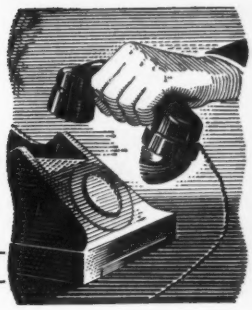

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Special Meeting in Austria, 1951

A Special Meeting of the Institute is to be held in Austria, from **5th to 18th September, 1951,** at the invitation of the Austrian Iron and Steel Institute.

Details have been circulated to Members who will attend the Meeting: an abridged programme was published in the August issue of the *Journal* (p. 407).

Autumn General Meeting, 1951

The Autumn General Meeting of the Institute will be held in London on **21st–22nd November, 1951.**

Symposium on the Corrosion of Buried Metals

A Symposium on the Corrosion of Buried Metals, organized by The Iron and Steel Institute in conjunction with the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry, will be held at the offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, on **Wednesday, 12th December, 1951**; Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., Director of the British Iron and Steel Research Association, will be in the Chair. The sessions will begin at 10.0 A.M. and 2.30 P.M. and will be open to all interested in the subject under discussion.

The papers will be presented in brief individually and discussed in groups, as indicated in the programme below.

The papers and the discussion will be issued as a single bound volume (No. 45 in the Special Report Series of The Iron and Steel Institute) the published price of which will be 15*s.* 0*d.* (post free). *Orders received before the Meeting, if accompanied by a remittance, will be supplied at the reduced rate of* 10*s.* 0*d.* *(post free), and one set of advance copies of the papers will be provided in respect of each volume so ordered, without extra charge.* Advance copies will not be supplied separately, nor will more than one set be provided in respect of each bound volume ordered before the Meeting.

PROGRAMME

Morning Session

10.0 A.M.—Opening remarks by the Chairman

10.05 A.M.—Joint discussion on:

"*Tests on the Corrosion of Buried Iron and Steel Pipes*," by J. C. Hudson and G. P. Acock

"*Investigations on Underground Corrosion*," by K. R. Butlin, W. H. J. Vernon, and L. C. Whiskin

11.45 A.M.—Joint discussion on:

"*Cathodic Protection*," by K. A. Spencer

"*Cathodic Protection of Buried Metal Structures*," by M. R. de Brouwer

1.30 P.M.—Buffet Luncheon in the Institute Library

Afternoon Session

2.30 P.M.—Joint discussion on:

"*Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils*," by G. Mole

"*Tests on the Corrosion of Buried Aluminium, Copper and Lead*," by P. T. Gilbert and F. C. Porter

4.30 P.M.—Conclusion of the Meeting

Changes on Council

Mr. I. F. L. ELLIOTT and Mr. N. A. ROLLASON have been nominated Vice-Presidents.

Professor J. H. ANDREW, D.Sc., and Sir Arthur MATTHEWS, O.B.E., have been nominated Honorary Vice-Presidents.

Mr. H. BOOT, Mr. E. T. JUDGE, and Mr. S. THOMSON have been nominated Members of Council.

List of Members

The List of Members and Associate Members of The Iron and Steel Institute (corrected to 31st May, 1950) is now available from the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, at the price of 5*s.* per copy.

Bibliographies

The following bibliographies prepared by the Library and Information Department are now available:

No. 3*a*—Design, Manufacture, Properties, and Uses of Ingot Moulds for Steel Ingots (Covering the Period 1935–1950).

No. 14*a*—Steel Converter Practice including Multiplex Processes (Covering the Period 1946–1950 and including some earlier references not mentioned in Bibliography No. 14).

No. 18—Segregation, Inclusions, Structure, and Piping of Steel Ingots (Covering the Period 1931–1951).

No. 19—Ingot Casting, Freezing, and Crystallization (Covering the Period 1931–1950).

Duplicated stencilled copies of these bibliographies may be obtained from the Secretary at 4 Grosvenor Gardens, London, S.W.1, price 2*s.* 6*d.* each (1*s.* 3*d.* to Members).

NEWS OF MEMBERS

▶ Mr. J. C. ARROWSMITH has taken up an appointment at the Pressed Steel Co., Ltd., Cowley, Oxford.

▶ Mr. V. T. BALASUBRAMANIAN is returning to Madras, India, where he will be in charge of the Foundry of The India Pistons, Ltd.

▶ Mr. M. F. BINNEY has left the British Iron and Steel Research Association to take up an appointment in the Chemical Engineering Section of the Research Department of Courtaulds, Ltd.

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▶ Mr. E. D. H. BOOTH has left the British Iron and Steel Research Association and has rejoined the Glengarnock Steelworks of Messrs. Colvilles, Ltd.

▶ Mr. C. L. M. COTTRELL has been appointed Assistant Chief Metallurgist for ferrous metals at the British Welding Research Association.

▶ Mr. H. R. CURNOCK has left Messrs. "Wilson's" Forge, Ltd., to take up an appointment as Chief Metallurgist with Darlington Wire Mills, Ltd.

▶ Mr. C. J. DANGERFIELD has transferred from the Research Laboratories to the Works of the British Aluminium Co., Warrington.

▶ Mr. H. E. DIXON has been appointed Chief Metallurgist for non-ferrous metals at the British Welding Research Association.

▶ Mr. A. G. DUCE has received the Ph.D. degree of the University of Cambridge.

▶ Mr. T. CAMPBELL FINLAYSON has been appointed Chairman of Woodall-Duckham, Ltd.; he is also Chairman of the Woodall-Duckham Vertical Retort and Oven Construction Co., Ltd.

▶ Dr. H. FORD has been appointed Professor of Applied Mechanics in the University of London. The appointment is tenable at Imperial College.

▶ Mr. F. B. GEORGE, Manager of Works Development, has been appointed a Local Director of Consett Iron Co., Ltd., Durham.

▶ Mr. V. C. HANSON has been appointed Managing Director of Messrs. Kent Alloys, Ltd., Rochester, Kent.

▶ Mr. K. G. HARRIS has been awarded the degree of B.Sc. (Hons. Met.) by the University of Wales and has also been elected a Licentiate of the Institution of Metallurgists. He has joined the metallurgical staff of Guest Keen Baldwins Iron and Steel Co., Ltd., Cardiff.

▶ Mr. J. L. HARRISON has joined the British Oxygen Co., Ltd., as an adviser and consultant on the use of oxygen in steelmaking processes.

▶ Mr. M. G. HIPKINS has left The Mond Nickel Co. and taken up an appointment with the Ministry of Supply, Division of Atomic Energy. He has become an Associate of the Institute of Metals.

▶ Mr. C. HIPWELL has taken up an appointment with Redpath Brown and Co., Ltd., London, W.C.2.

▶ Mr. A. KIRKWOOD will be leaving South Africa to work in India with the International Construction Co.

▶ Mr. T. McHUGH has been appointed Metallurgist with the Low Moor Alloy Steelworks, Ltd.

▶ Mr. JAGDISH MARWAHA has received the degree of B.Sc. in Metallurgical Engineering from Benares Hindu University.

▶ Mr. H. R. MASON has received the degree of B.Sc. in Metallurgy and Chemistry from Melbourne University. He has taken up an appointment with Broken Hill Co. Pty., Ltd.

▶ Mr. D. MAXWELL has recently received the degree of M.A. of the University of Cambridge and is now engaged in research work in the Inorganic Chemistry Department of the University of Durham.

▶ Mr. A. RAMSAY MOON has left Toronto, Canada, and is now living in Victoria, Australia.

▶ Dr. EGON OROWAN has been appointed George Westinghouse Professor of Mechanical Engineering at the Massachusetts Institute of Technology, U.S.A.

▶ Mr. A. R. PALMER will shortly be leaving England to take up an appointment with the Colonial Development Corporation in Tanganyika.

▶ Mr. J. A. ROBERTS has taken up an appointment with the Light Alloy and Fabricating Section of Messrs. Richard Thomas and Baldwins, Ltd., Swansea.

▶ Mr. H. A. SCHWARTZ has been awarded the 1951 Charles H. McCrea Medal by the National Malleable and Steel Castings Co., Ohio, for his contribution towards progress and development in the Malleable Iron Industry.

▶ Mr. H. G. V. SENTANCE has retired from the combined firms of Davy Bros., Ltd., (now Davy and United Engineering Co., Ltd., of Sheffield) and Duncan Stewart and Co., Ltd., Glasgow.

▶ Mr. A. P. SUDARSANAN has been awarded a B.Sc. degree in Metallurgy. Until next January he will be working at Deutsche Edelstahlwerke A.B., Krefeld, Germany.

▶ Mr. THEODOR E. SUESS has been awarded the Doctorate of Technical Sciences at the Technische Hochschule, Vienna.

▶ Dr. C. SYKES has been appointed Managing Director of the Brown-Firth Research Laboratories, Sheffield.

▶ Mr. O. J. THOMAS has been appointed a Director of the Glynhir Tinplate Co., Ltd., Swansea.

▶ Mr. H. V. TOMLINSON, Manager of Works Production, has been appointed a Local Director of Consett Iron Co., Ltd., Durham.

▶ Dr. E. T. TURKDOGAN has been awarded the Brunton Medal by Sheffield University for the best original research in metallurgy of the year. The work was carried out with the aid of a grant from the Andrew Carnegie Research Fund.

▶ Mr. J. VEVERS has taken up an appointment with Simon Carves (Africa) Pty., Ltd., Johannesberg, South Africa.

▶ Mr. H. VICKERS has taken up an appointment in the Division of Atomic Energy of the Ministry of Supply.

▶ Mr. P. WATSON has left the South Durham Steel and Iron Co., Ltd., to take up an appointment with Imperial Chemical Industries, Ltd., Manchester.

▶ Mr. H. WILLNERS has left Aktiebolaget Metallurgisk Industri, Trollhättan, to take up an appointment with Aktiebolaget Ferrolegeringar, Stockholm.

▶ Mr. C. V. WILSON has left the Research Laboratories of Messrs. Rolls Royce, Ltd., Derby, to take up an appointment as Assistant Manager of Messrs. N. C. Ashton, Ltd., Huddersfield.

▶ Mr. GEORGE WOOD, Chairman of Thos. W. Ward, Ltd., Albion Works, Sheffield, has been awarded the C.B.E.

Obituary

Mr. H. J. HOBSON, Assistant Engineer at Samuel Fox and Co., on 26th June, 1951.

CONTRIBUTORS TO THE JOURNAL

H. M. Finniston, B.Sc., Ph.D.—Head of the Metallurgy Division of the Atomic Energy Research Establishment at Harwell. Dr. Finniston was born in 1912 and educated in Glasgow where he attended the University and the Royal Technical College. He graduated with First Class Honours in Metallurgy in 1933 and, after four years with Messrs. Stewarts and Lloyds, Ltd., he returned to Glasgow as Chief Research Officer of the Scottish Coke Research Committee.

In 1940 he received a Ph.D. degree, and took charge of the Metallurgical Section of the Bragg Laboratory of the Naval Ordnance Inspection Department, Sheffield; he was seconded by the Royal Naval Scientific Service in 1946 to the Department of Atomic Energy. On his return from Canada, where he organized the metallurgical side of the atomic energy work, he became Deputy Head of the Division at Harwell and was appointed to his present post in 1948. He is Chairman of the Oxford Local Section of the Institute of Metals.

K. H. Jack, M.Sc., Ph.D.—Lecturer in the Chemistry Department of King's College, University of Durham.

H. M. Finniston

K. H. Jack

Dr. Jack graduated at this college in 1939 and returned as Demonstrator in 1941 after a period in the Ministry of Supply. In 1943 he was appointed Lecturer in Physical Chemistry. He joined the British Iron and Steel Research Association in 1945, working first at Newcastle and then, from 1947 until 1949, at the Crystallographic Laboratory of the Cavendish Laboratory, Cambridge, where he obtained the degree of Ph.D. His main work has been on the interstitial alloys of iron, cobalt, and nickel, and in particular on new phases of potential technical significance in the iron–nitrogen and iron–carbon–nitrogen systems. This research is now being continued in the Chemistry Department of King's College, to which he returned as a lecturer in 1949.

T. E. Dancy, Ph.D., D.I.C., A.R.C.S.—Scientific Officer in the Iron-Making Division of the British Iron and Steel Research Association. Dr. Dancy was born in 1925 and was educated at Highgate School and at the Royal College of Science where he obtained a B.Sc. degree in Chemistry and became an Associate in 1945. For the next two years he was working on Fuel Technology under Professor Himus at Imperial College, London, and was awarded the Ph.D. degree and the D.I.C. in 1947. Later, in the same year, he joined the British Iron and Steel Research Association. He is a member of the International Committee for Research on Low-Shaft Blast Furnaces.

IRON AND STEEL ENGINEERS GROUP

The **Sixteenth Meeting** of The Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 4th December, 1951.**

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Junior Steelmaking Conference

The Fifth Junior Steelmaking Conference was held at Ashorne Hill in June. During the first session Dr. T. P. Colclough presented a paper on the effect on the output of steel of present-day trends in the supply of raw materials. Later, Dr. J. H. Chesters and Mr. J. Mitton spoke of some aspects of all-basic open-hearth furnace practice.

AFFILIATED LOCAL SOCIETIES

Staffordshire Iron and Steel Institute

Mr. K. H. WRIGHT will continue in office as President of the Staffordshire Iron and Steel Institute until April, 1952.

If there is sufficient support, the Staffordshire Iron and Steel Institute proposes to organize for its members a long week-end trip to Paris during the last week in September or the first week in October. It would include a trip to one of the works in the immediate neighbourhood, possibly the Citroën works.

Lincolnshire Iron and Steel Institute

Mr. A. JACKSON has been re-elected President of the Lincolnshire Iron and Steel Institute for the Session 1951–52.

Ebbw Vale Metallurgical Society

The list of Officers for the Session 1951–52 is as follows :

President

F. E. PROBYN

Vice-President	**Treasurer**
W. D. JENKINS, B.Sc.	H. EVANS

Hon. Joint Secretaries

R. C. POWELL, B.Sc. W. B. WILLIAMS

Committee

J. J. BEESE	D. A. JENKINS
W. H. R. BIRD, M.A., B.Sc.	F. W. LEWIS
J. BLAIR	F. LLEWELLYN
G. CAMPBELL, B.Sc.	A. J. MEO
W. J. DAVIES	H. F. PADBURY
P. EDWARDS	W. SHEARER
A. W. ELLIS	J. F. SMITH
I. GIDDINGS	J. H. STEELE

Mr. R. A. HACKING, O.B.E., M.Sc., has been appointed to represent The Iron and Steel Institute on the Committee.

MEMOIR

Herbert Kilburn Scott was born in Leeds in 1870 and educated at Yorkshire College. He served an apprenticeship with Messrs. R. Kilburn, Iron Founders, Leeds, before joining the firm of William Riley (Analysts) where he was employed in connection with the iron ore deposits on the Island of Elba. He was later appointed Mine Manager at Minas Geraes, Brazil. He relinquished this post to practise as a consulting mining engineer first in Rio de Janeiro and later in London. He visited many countries in the course of his work, and was the author of many technical papers including one on the mineral resources of Yugoslavia. During the First World War he served in the Northumberland Hussars. He was subsequently appointed Director of Mineral Resources in the Midlands. He became a Member of The Iron and Steel Institute in 1896 and was elected a Life Member in 1947. He was also a member of the Institution of Mining and Metallurgy and a member of the French Society of Civil Engineers. Mr. Scott died on 24th October, 1950.

NEWS OF SCIENCE AND INDUSTRY

International Congress of Industrial Chemistry

The 24th International Congress of Industrial Chemistry will be held in Paris from 25th November to 1st December, 1951. In connection with the Congress, the Société of Chimie Industrielle, is holding a chemical exhibition of research work and apparatus, from 22nd November to 2nd December.

Further particulars may be obtained from the Société de Chimie Industrielle, 28 rue Saint Dominique, Paris.

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Spanish Institute of Welding

The closing date for the submission of papers for the Third Welding Competition to be held by the Spanish Institute of Welding (*see* March, 1951, issue of the *Journal*, p. 323) has been extended to 30th September, 1952.

Conservation of Scarce Materials

The Anglo-American Council on Productivity has recently sent to the United States a specialist group on conservation of scarce materials. This Group enquired into measures being taken and planned in the engineering and allied industries in the United States for the conservation and efficient utilization of scarce materials. It was concerned primarily with the immediate short-term problem but wished also to be put in touch with any long-term steps (involving basic changes in design) being currently planned.

The Group, which was led by Sir Graham Cunningham, K.B.E., LL.B., left England by air on 17th June and returned on 13th July, 1951. Mr. D. A. Oliver (Member of Council), Metal Economy Adviser to the Ministry of Supply and Director of Research of the B.S.A. Group Research Centre, and Major P. L. Teed (Member), Deputy Director of Aircraft Research and Development, Vickers-Armstrongs, Ltd., were members of the Group.

Iron and Steel Productivity Team

The Iron and Steel Productivity Team representing the British heavy steelmaking industry returned from the United States on July 5th after spending five and a half weeks visiting steelworks in California, Texas, and Colorado, as well as the traditional steelmaking areas in the East.

The Team found that high productivity in the American industry is primarily due to (*a*) the size of the plant units, (*b*) the purity of raw materials (resulting in a low metallurgical load), (*c*) the tendency to drive units fast, and (*d*) the use of high-grade fuel, including natural gas and fuel oil.

The training of employees, other than those of supervisory grades, is less developed, and incentive wage schemes are not used so extensively as in Britain.

The report of the Team, which includes many points of interest in blast-furnace, O.H. furnace, and rolling-mill design and operation, will be published in due course.

Pressed Metal Industry

The second of the Productivity Teams from America to pay a reciprocal visit to the United Kingdom has completed a five weeks' tour of British factories. The visit is a sequel to the visit to the U.S.A. of the Productivity Team from Britain in 1949.

The team, led by Mr. F. C. Greenhill, President of the Acklin Stamping Company, of Toledo, Ohio, has expressed keen interest in the methods and techniques of production brought to its notice, commenting that in some cases there is a great similarity between British plants and those in operation at, say, Detroit.

Steel Company of Wales, Ltd.

After more than four years of intensive construction, the 80-in. continuous strip mill at the Abbey Works has come into operation. The inaugural ceremony was held on 17th July, 1951, with the Chancellor of the Exchequer, the Rt. Hon. Hugh Gaitskell, as the principal guest.

During the period of reconstruction, which has produced the integrated works of Port Talbot, Margam, and Abbey, the three blast-furnaces at Margam have been enlarged to produce a total of 2700 tons of iron per day. New coke ovens have been built, which will eventually provide 15,000 tons of coke per week. The limestone quarries at Cornelly have been completely mechanized, and the facilities for handling foreign ores at the wharf have been considerably increased. At Port Talbot and at Margam, the O.H. furnaces are being reconstructed as 80-ton fixed furnaces. Of 12 original furnaces nine have already been built.

In the new melting shop at Abbey, four 200-ton fixed oil-fired furnaces have been built and four more are being constructed. Hot metal from the blast-furnaces is stored in two 800-ton mixers.

At the end of the slabbing mill 12 new soaking pits are in operation and eight more are being built. Three reheating furnaces have been installed for the Hot Strip mill and a fourth is to be installed later. After passing through four roughing stands the slabs are held on a delay table before entering the first of the size finishing stands. Two down-coilers, of the collapsing mandrel type, provide 27,000-lb. coils for cold reduction. At present, the finished coils will be despatched to other works for further treatment, until the Cold Reduction mills at Margam and Trostre are in operation.

The estimated weekly output of the plant is : coke, 15,000 tons ; iron, 19,000 tons ; steel ingots, 30,000 tons. The plant will roll 3500 tons of rails, etc., and 22,800 tons of steel strip and plate per week, of which 7000 tons will be sent to Trostre for tinplate manufacture.

After the plant has been in operation for some time, it is hoped to give detailed descriptions and operating data of the various items in the Iron and Steelworks Engineering Section of the *Journal*.

DIARY

30th Aug.–13th Sept.—ENGINEERING, MARINE, AND WELDING EXHIBITION—Olympia, London, W.14.

3rd–15th Sept.—AMERICAN CHEMICAL SOCIETY—International Union of Pure and Applied Chemistry—Anniversary of Bureau of Standards.

5th–18th Sept. — IRON AND STEEL INSTITUTE — Special Meeting in Austria.

6th–15th Sept.—SUMMER SCHOOL ON THE PHYSICS OF SOLIDS—H. H. Wills Physical Laboratory of the University of Bristol.

10th–14th Sept.—INTERNATIONAL FOUNDRY CONGRESS —Association Technique de Fonderie de Belgique—Fédération des Entreprises de l'Industrie des Fabrications Métalliques A.S.B.L., Fabrimental building, 21 rue des Drapiers, Brussels, 9 a.m.

11th–13th Sept.—INSTITUTION OF MECHANICAL ENGINEERS—General Discussion on Heat Transfer—Storey's Gate, S.W.1.

11th–20th Sept.—CONGRESS ON BUILDING RESEARCH—London.

16th–25th Sept.— INSTITUTE OF METALS — Annual Autumn Meeting in Italy.

TRANSLATION SERVICE

(The previous announcement was made in the August, 1951, issue of the *Journal*, p. 410).

TRANSLATION AVAILABLE

No. 423 (Czech). A. BENDA : "Thermal Analysis of Open-Hearth Furnace Operation." (*Hutnické Listy*, 1950, vol. 5, Nov., pp. 454–457).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

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MINERAL RESOURCES

Sweden's Arctic Iron Mines. F. Illingsworth. (Mine and Quarry Engineering, 1950, vol. 16, Dec., pp. 387–390). The Arctic iron mining town of Kiruna stands on the shores of a lake 100 miles north of the Polar Circle and on the railway between Luleå and Narvik. The ore deposits consist of masses of magnetite with some apatite, associated with syenite porphyries. Hitherto only the shallower ore bodies have been worked but good headway is now being made in the sinking of a shaft to open up the huge reserves at a depth of 1500 ft. beneath the lake.—E. C. S.

India, The Gold Coast, The Union of South Africa and Brazil Co-operate in the American Battle for Manganese. L. Catriu. (Mineração e Metalurgia, 1951, vol. 15, Jan.–Feb., pp. 223–224). [In Portuguese]. A compact survey is given of Brazilian manganese deposits and the policy of development in relation to North American needs.—R. S.

Cerro Bolivar—Saga of an Iron Ore Crisis Averted. T. W. Lippert. (Journal of Metals, 1950, vol. 188, Feb., pp. 222–236; Mining Engineering, 1950, vol. 187, Feb., pp. 178–192). The present and future position in iron ore supplies for the U.S.A. are discussed in some detail. Home and foreign sources are considered and economic factors involved in future utilization of concentrates from low-grade Mesabi ores are surveyed. An outline is given of a world-wide post-war search for further ore supplies, the search culminating in the discovery of very rich deposits in Venezuela. The planned development and exploitation of these deposits are outlined.—E. C.

Fourth Brazilian Congress on Geology. (Mineração e Metalurgia, 1950, vol. 15, Nov.–Dec., p. 156). [In Portuguese]. The official institutions and personalities taking part in the Fourth Congress of the Brazilian Geological Society on 4th Nov., 1950, are listed. The main theme was the study of the central regions of Minas Geraes. Visits to the pyrites deposits in Ouro Preto, iron ore deposits of Casa de Pedra, and the manganese deposits of Morro da Mina are briefly described. No technical details are given.—R. S.

ORES—MINING AND TREATMENT

Mining in Vizcaya. (Boletin Minero e Industrial, 1951, vol. 30, Jan., pp. 27–32). [In Spanish]. The report of the Technical Committee for the Study of Iron Ore Deposits of the Vizcaya-Santander zone is reviewed. This describes the geology and the results of borings. It is now intended to transfer investigations to the Bodovalle area.—R. S.

Mining and Metallurgical Industry of Vizcaya in 1949. (Boletin Minero e Industrial, 1951, vol. 30, Jan., pp. 17–25). [In Spanish]. The reasons for the deterioration in development of the Biscay mining industry are given. Factors discussed include labour, productivity, electric power, coal, transport, and amortization. Outputs of the various mines and details of new plants authorized in 1949 are presented. R. S.

Iron Ore in Canada: Development of the Quebec-Labrador Deposits. (Monthly Review of the Bank of Nova Scotia: British Steelmaker, 1951, vol. 17, Feb., pp. 82–85). This article summarizes the plans to develop the high-quality iron-ore deposits on the Quebec-Labrador frontier, estimated to exceed 400 million tons. The construction of a 360-mile railway northwards from the Gulf of St. Lawrence has been started, and shipments of ore are expected to begin in 1954, and may total 10 million tons annually by 1956.—G. F.

Aktieselskapet Titania. J. Lenshow. (Tidsskrift för Kjemi, Bergvesen og Metallurgi, 1950, vol. 10, Mar., pp. 146–149). [In Norwegian]. The methods of mining and concentration employed by this company to exploit their ore field at Sokndal near Egersund, South Norway, are described. The ore contains about 17% TiO_2 and 20% Fe. In the five years 1945–49, 1,314,157 metric tons of ore were treated and yielded 337,614 tons of ilmenite concentrate (44% TiO_2) and 69,595 tons of magnetite concentrate (2·70% TiO_2, 66% Fe). Ore is crushed in three stages, to 150 mm. in jaw crushers, to 10 mm. in cone crushers, and 1·5 mm. by wet grinding. At a later stage the magnetite is ground to 100 mesh. The 1·5-mm. material is freed from gangue by table washing. The magnetite is separated from the ilmenite by Löwenhielm wet magnetic separators. New treatment plants were set up in 1930 and 1946. The total capacity is now 100,000 tons of ilmenite per annum and the plant includes a 36-in. × 48-in. heavy crusher, a 7-ft. Symons standard cone crusher, a 5-ft. 6-in. Symons short-head cone crusher, four rod mills, 90 washing tables, 14 magnetic separators, and 10 Wetherill separators. This plant employs 30 men and various trials at present require 18 more. The power consumption for the treatment of 400,000 tons of crude ore per annum is about 12,000,000 kWh. A flow sheet is shown.—R. A. B.

Comminution Plant. F. Lebeter. (Mine and Quarry Engineering, 1950, vol. 16, Sept., pp. 273–276; Oct., pp. 327–330; Nov., pp. 355–358; Dec., pp. 391–394). Crushing is the process of reducing to a particle size of the order of 1 in. to $\frac{1}{8}$ in., whereas reduction below $\frac{1}{8}$ in. is generally known as grinding. Part I deals with the choice of suitable crushers

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and describes the Symons cone crusher. Part II deals with gyratory crushers, jaw crushers, and ball mills; Part III with the optimum speed of revolution of a ball mill and the uses of rod mills, conical ball mills, gravity stamps, rolls and hammer, and Lopulco-type crushers; finally, in Part IV recommendations on the lubrication of crushers and grinding mills are made.—E. C. S.

A Theory of Fluidization and Its Application to Sulphur Recovery by Solvent Extraction. E. Johnson. (Institution of Gas Engineers, Institution Gas Research Fellowship Report 1949–50, Copyright Publication No. 378/179). Previous work on the fluidization of solid particles with air and water is reviewed and a mathematical theory of the mechanism of fluidization is advanced. Experimental data are presented in respect of carborundum, coke, alumina, and spent oxide fluidized by air, water, and a glycerine–water solution. The effects of particle size, solid density, fluid density, fluid viscosity, and bed mass were investigated in turn. A large-scale fluidized process is proposed for extracting sulphur from spent oxide.—R. A. R.

Chemico-Physical Research on Specimens of Sintered Purple Ore. A. Molaroni. (Metallurgia Italiana, 1951, vol. 43, pp. 74–80). A description is given of the results obtained by the application of metallographic methods to the study of purple-ore sinters. Analysis of these sinters with the microscope has enabled the true proportion of the various phases (oxide, slag) to be assessed and also their relative distribution in the structure and the presence of the various iron oxides. It has been possible to obtain data which confirm the results obtained by chemical and other methods of analysis.

M. D. J. B.

Beneficiation of Adirondack Magnetite. W. R. Webb and R. G. Fleck. (Mining Engineering, 1950, vol. 187, Apr., pp. 444–448). Mining of low-grade magnetite ore in the Adirondack district is being resumed on an increasing scale, a concentrate sinter for blast-furnaces being the final product. A typical operational sequence is outlined, including open-cast mining, gyratory and cone crushing, fine grinding in rod and ball mills, and conventional primary and secondary magnetic concentration. An average iron content of 24% as mined is brought to 63·75% in the concentrate. Non-magnetic ores are not being utilized at present, but successful trials have been made with Humphrey spiral concentrators.—E. C.

Future of the Iron and Steel Industry in Spain. B. Chavarri. (Boletin Minero e Industrial, 1951, vol. 30, Jan., pp. 1–6). [In Spanish]. Spanish ores are briefly described and the problems of beneficiation reviewed. The costs of ingot manufacture from Asturian and Mesabi ores are compared. The metallurgical potentiality of the Asturian region is emphasized.—R. S.

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel Oil Flow: Metering Orifices for Use at Low Reynolds Numbers. J. A. Leys. (Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 373–375). The author describes the theory and experimental procedure involved in the development of an orifice suitable for metering fuel oil to open-hearth furnaces. The orifice is suitable for use within the range of Reynolds numbers of 300 to 10,000, with an accuracy of $\pm 2\frac{1}{2}\%$, and has the following characteristics: Orifice to pipe diameter ratio, 0·2; thickness to diameter ratio, 0·25; discharge coefficient, 0·78; and a semi-circular profile.—G. F.

Automatic Control for Multiple Fuel-Fired Boilers. M. J. Boho. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 96–99). Descriptions are given of automatic starting and stopping of pulverized coal burners to supplement blast-furnace gas firing. The measurements of fuels through multiple burners and of fuel/air ratio are considered as well as totalizing apparatus and high-speed diaphragm-type metering regulators.—M. D. J. B.

Assessment of Heat Exchangers. H. Kühne. (Chemie, Ingenieur, Technik, 1950, vol. 22, Apr. 28, pp. 168–171). In view of the wide variety of heat-exchange systems, a satisfactory method of comparison was desirable in order to determine the most suitable system for any given purpose. The author derives a function of comparison from pressure drop, heat transfer, and ratio of throughput per hour to surface area, the function being independent of the process in which the heat exchanger is used. The function may also be used for determining conditions under which a given heat exchanger will work most efficiently.—E. C.

Development of Furnace Design in the Metallurgical Industry During the Last Thirty Years. M. Golosman. (Hutnické Listy, 1950, vol. 5, Dec., pp. 515–520). [In Czech]. The principal Russian developments in design and construction of furnaces for the metallurgical industry, mainly the iron and steel industry, are briefly described. The author reviews the main Russian trends in improving the combustion efficiency of gaseous fuels, the transfer of heat, developments in mechanization and automatic controls, regenerators, recuperators, auxiliary equipment, and the use of protective atmospheres. Russian trends in the design of soaking pits, continuous furnaces for heating ingots and other products to be rolled or heat-treated are described in greater detail. Data are given on the capacities and dimensions of the most important types of furnace and on the fuels used. Drawings of some recent designs of furnace are also included.—E. G.

Laboratory Control in Coal Washing and Drying Plants. J. J. Merle and A. Mullins. (Mining Engineering, 1950, vol. 187, May, pp. 609–615). A detailed account is given of laboratory facilities and methods used at Ayrshire Collieries Corp., Illinois. Close product control in the coal-washing plant is achieved, economical operation is maintained, and the laboratory services are regarded as having considerable sales-promoting value.—E. C.

Quantitative Efficiency of Separation of Coal Cleaning Equipment. W. W. Anderson. (Mining Engineering, 1950, vol. 187, Feb., pp. 256–264). A formula for quantitative efficiency evaluation is proposed, the efficiency value being a function of the improperly distributed material at the gravity of separation effected by the cleaning equipment. The misplaced material is expressed as a percentage of the total material discharged from the equipment. Numerous examples are given, demonstrating application of the formula to various types of separation, including multiple-product separations.—E. C.

Systematic Control in the Operation of a Flotation Plant. H. Da Lage. (International Conference on Coal Preparation, Revue de l'Industrie Minerale, 1951, vol. 31, Jan., pp. 297–312). A tentative method of direct control by normal means is described followed by an account of systematic laboratory tests on the effect of single variables. Factors studied include: Choice of frothing and collecting agents, their optimum proportions, the effect of raw coal size and density, and the size analysis of the floats. The application of these results to plant control has reduced losses, improved the quality of product, and eliminated irregularities of working.—A. G.

The Mechanism of Coarse Coal and Mineral Froth Flotations. Shiou-Chuan-Sun and R. E. Zimmerman. (Mining Engineering, 1950, vol. 187, May, pp. 616–622). Results of studies of froth flotation of coal particles in size ranges greater than 35 mesh are presented, and a 'multi-bubble' hypothesis is put forward to explain the phenomena observed. Maximum size ranges for flotation of bituminous and anthracite coals are established, and factors affecting such flotation are analysed.—E. C.

Ash-Free Coal for Industrial Uses. H. G. Reyes. (Metalurgia y Electricidad, 1950, vol. 14, Dec., pp. 48–56). [In Spanish]. The nature and composition of primary and secondary ash are described. Wet and dry gravity methods, sink and float, and froth flotation methods of coal washing are discussed. Work carried out by Ougrée-Marihaye is described and the plant used is illustrated. The yield of pure coal is, however, small (about 40%) and there are considerable residual fines (under 0·5 mm.) containing double the percentage of ash compared with the original coal.—R. S.

Coal Washing and Preparation at North Gawber Colliery. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 2, pp. 263–267). A detailed and illustrated description is given of the new standard coal washing and preparation plant installed by the National Coal Board at North Gawber Colliery, which handles raw coal from dust to 6 in. at the rate of 200 tons/hr. Separation of the coal from the reject fractions is effected in a Norton balanced-density washer, and fines are treated in a "Knapp and Bates" froth-flotation unit.—G. F.

Inland Installs New Coal Preparation Plant. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 112–116). A description is given of the new coal preparation plant at Price, Ky., which, it is claimed, enables Inland Steel Co. to reduce the cost and increase the production of pig iron. The plant has a capacity of 750 tons of raw coal per hour. Slate, rock, fireclay, and other impurities are mechanically removed. A

comprehensive system of blending bins, paddle mills, and conveyors permits the automatic mixing of sizes and analyses for delivery to railway wagons.—M. D. J. B.

Modern Coal Preparation in the United States. C. W. Waterman, jun. (Mining Society of Nova Scotia; Canadian Mining and Metallurgical Bulletin, 1951, vol. 44, Jan., pp. 10–14). Mechanical cleaning is carried out predominantly by Baum-type jigs, the most important being the McNally-Norton Baum-type jig and the McNally-Mogul Baum-type jig, of which the latter is capable of handling wide size ranges. There is a downward trend in dry-cleaning installations, but one recent development, the McNally-Brusset vacuum jig is described. Drying is usually carried out by a screen type of drier, such as the McNally-Carpenter centrifugal drier, or the C.M.I. screen-type drier. Where absolute control of both ash and moisture is necessary, thermal drying is employed. Stage crushing is the best method, and a typical installation is shown. Finally, three outstanding plants are briefly described.—T. E. D.

Substitution of Pulverized Coal for Oil in the Heating of Industrial Furnaces. A. E. Nickěvič. (Za Ekonomiu Topliva: Hutnické Listy, 1951, vol. 6, Jan., pp. 49–50). [In Czech]. Experiments were carried out at a plant in the Urals with pulverized coal plus blast-furnace gas in various furnaces, including open-hearth furnaces. The experiments were carried out for 32 months with a mixture of blast-furnace gas and oil and for 25 months with a mixture of blast-furnace gas and pulverized coal (25%). The output of the furnace increased by 3% and the fuel costs per ton of steel were reduced by 10% when adding pulverized coal instead of oil to the blast-furnace gas.—E. G.

Operation of Metallurgical Furnaces with Pulverized Fuel. F. G. Titěnkov and L. G. Ardašnikov. (Za Ekonomiu Topliva: Hutnické Listy, 1951, vol. 6, Jan., p. 50). [In Czech]. From 1947 onwards experiments were carried out in heating large castings with pulverized coal. The plant used for burning the pulverized coal is described in detail. Compared with producer-gas operation, the cost of the plant is less than half and the saving of fuel about 20%. This fuel should be applied more extensively in furnaces intended for heat-treating metals, and in open-hearth furnaces.—E. G.

Pulverized Coal Firing of Heating Furnaces in the Iron and Steel Industry. K. Kessels. (Stahl und Eisen, 1951, vol. 71, Jan. 18, pp. 53–62). One of the ways in which the acute shortage of gas for firing purposes can be overcome is to employ pulverized fuel. The present-day economic and technical status of this method of heating in the iron and steel industry is reviewed. Fuel preparation, storing, transport, and pulverized-fuel furnaces are discussed at length and relevant operational data given. Since most of this concerns older plants, it is to be expected that great progress will be made in the future, particularly in regard to cleanliness. The comparative cost of heat generated from mains gas and pulverized coal is a strong incentive towards the use of the latter.—J. P.

Gas Supply in the Iron and Steel Industry and New Methods of Gasification of Solid Fuels. Z. Warczewski. (Hutnik, 1951, vol. 18, Feb., pp. 61–68). [In Polish]. Some economic and technical aspects of the gasification of solid fuels using: (*a*) oxygen enrichment; (*b*) increased pressure; (*c*) suspended fines; and (*d*) underground gasification are discussed.—V. G.

The Problem of Coking Coals in Poland. A. Bolewski. (Hutnik, 1951, vol. 18, Jan., pp. 1–6). [In Polish]. Present output of coking coal in Poland and its future possibilities are discussed.—V. G.

Controlled Cooling of a Koppers-Becker Battery. J. D. Price. (Eastern States Blast Furnace and Coke Oven Association and Chicago District Blast Furnace and Coke Association: Blast Furnace and Steel Plant, 1951, vol. 39, Feb., pp. 203–213). A Koppers-Becker battery at the Colorado Fuel and Iron Corporation was cooled down uniformly along its length at about 30° F. per day; at the inversion from beta to alpha cristobalite the temperature gradient was levelled off for a few days. Vertical cracks occurred in the oven walls but the battery could again be operated successfully.
E. J. B.

REFRACTORY MATERIALS

Refractories Problems in Industry. T. P. Mann. (Australian Institute of Metals: Australasian Engineer, 1951, Feb. 7, pp. 83–88). The many tests which are carried out in order to assess the characteristics of refractory materials are listed and briefly described, and the most suitable equipment and procedure is indicated in each case. By referring to several specific examples, the author then discusses the selection of the most suitable refractory for each job, the investigation of inferior service behaviour, and the evaluation of new refractories.—P. M. C.

Refractory Products, Their Properties and Principal Uses. J. Kratzert. (Neue Giesserei, 1950, vol. 37, Sept. 7, pp. 360–364). The physical, mechanical, and chemical properties and applications of silica, fireclay, high-alumina materials, mullite, corundum, magnesite, chromite, chrome-magnesite, dolomite, carborundum, and coke are reviewed.—J. P.

Control of Refractory Materials. C. E. Sumpter. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, 1950: Journal of Metals, 1950, vol. 188, Dec., pp. 1442–1443). The author briefly reviews the refractory materials used in the construction and maintenance of electric furnaces, and the methods of checking and controlling their quality. The desired properties of magnesite, basic ramming materials, and clinkered dolomites are tabulated, and brief details are given of an initial trial of a 13½-in. mullite-base brick roof on a furnace producing stainless steels, which lasted more than three times longer than an 18-in. silica roof.—G. F.

Economic and Metallurgical Advantages of Chrome-Magnesite over Silica as an Open-Hearth Furnace Lining. P. Bremer. (Stahl und Eisen, 1951, vol. 71, Jan. 18, pp. 64–71). On the basis of a comparison of material and wages costs in the rebuilding and repairs of a 40-ton open-hearth furnace with chrome-magnesite or silica bricks, it is shown that the all-basic construction is somewhat cheaper. When the economy in heating over a three-year period is taken into account, the all-basic shows an overall saving of some 25% as compared with silica furnaces. Chrome-magnesite also has metallurgical advantages, manganese and chromium yields being higher.—J. P.

Carbon Disintegration Test for Blast-Furnace Brick. L. J. Trostel. (Journal of the American Ceramic Society, 1951, vol. 34, Mar., pp. 76–81). Apparatus and procedure are described for testing the disintegration resistance of blast-furnace brick, using bottled CO. Simple automatic operation permits test periods up to 1000 hr. with up to 60 specimens at a time. Cone-12 brick failed structurally after 50 hr., cone-18 brick were unaffected after a 500-hr. test. Losses in cold-crushing strength, modulus of rupture, and elasticity appear to have no application as criteria in this type of test except for revealing residual strengths after periods of exposure. The method described is costly at present and not routine in character.—E. C.

The Uses of Graphite and Carbon in the Engineering and Metallurgical Industries. R. Ogilvy. (Australian Institute of Metals: Australasian Engineer, 1951, Jan. 8, pp. 80–89). Carbon and graphite, when processed or incorporated with other materials, may be endowed with a wide range of most useful properties, including good mechanical strength, chemical inertness, refractoriness, resistance to wetting by molten metals, self lubrication, etc. The author reviews the many uses of these materials in the steel, chemical, mechanical, and electrical industries. The lining of blast-furnaces and chemical-reaction chambers, and the performance of carbon bearings, gland rings, piston rings, and electric current collectors and brushes are among the many applications dealt with in detail. Useful tables are given which list mechanical, physical, chemical, and refractory properties of British carbon bricks. The resistance to chemical attack of specially developed carbon cements is also tabulated.—P. M. C.

The Manufacture of Linings for Basic-Bessemer Converters. J. Massinon. (Revue Technique Luxembourgeoise, 1951, vol. 43, Jan.–Mar., pp. 13–30). For use as a basic lining the raw dolomite must contain less than 19·5% MgO and a maximum of 4% impurities. The heat-treatment of the dolomite is as follows: (1) Removal of moisture. (2) Calcination between 600–1000° C. resulting in increased porosity. (3) Ignition from 1200° C. reducing the porosity and leading to partial combination of the impurities with MgO and CaO. (4) Cooling in an oxidizing or reducing atmosphere. Hydration of the dolomite by atmospheric moisture causes breakdown of the material with the production of dust. This is due to the lime in the dolomite but research has shown that the addition of 0·16% stearic acid added at the crushing stage forms a protective

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layer around the particles and has resulted in substantial improvement. Crushing trials have been carried out and the importance of careful size grading is stressed. In 1941 a commission was set up to try to standardize the tar used as a binder and details are given of some of their results. Investigation of the correct tar/dolomite ratio for maximum cohesion shows that there is an optimum value for 5% tar. The optimum value of tar for maximum crushing strength varies with the particle size. An empirical relationship between tar viscosity and the optimum tar concentration has been obtained. Research into the firing of dolomite has shown that it is better to try to reduce the final firing temperature necessary for sintering by addition of SiO_2, Al_2O_3, or Fe_2O_3 than to ignite to too high a temperature.—B. G. B.

Mineral and Chemical Changes in Periclase Brick under Conditions of Steel Plant Operation. R. G. Wells and L. H. Van Vlack. (Journal of the American Ceramic Society, 1951, vol. 34, Feb., pp. 64–70). A number of chrome-magnesite and periclase bricks from a basic open-hearth furnace were examined. Alterations in chemical nature and mineral composition, corresponding to a marked colour zoning, were noted. They are regarded as resulting from the thermal gradient across the bricks and from absorbtion of material from the furnace atmosphere. A silicate liquid, found to form a network surrounding the periclase grains and preventing contact between them, is the suggested cause of cracking of bricks leading to major losses due to spalling. E. C.

A High-Lime Refractory Resistant to Phosphate Melts—Studies in the System CaO–TiO_2. H. G. Fisk. (Journal of the American Ceramic Society, 1951, vol. 34, Jan. 1, pp. 9–13). Experimental preparation of refractory crucibles resistant to phosphate melts, their properties, and mineral composition are described. Prepared from lime bonded with calcium titanate, the crucibles exhibited good spalling resistance and a relatively good stability to the slaking action of the atmosphere. The crystalline calcium titanate forming the bond between, and protective coating on, the lime grains is thought to be $3CaO.2TiO_2$. Its optical properties, lattice spacings, and melting behaviour are described.—E. C.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Use of Magnetic Ores from New York State. K. G. LeVisuer. (American Iron and Steel Institute : Blast Furnace and Steel Plant, 1951, vol. 39, Feb., pp. 200–202). With the diminishing supply of good metallurgical coal and the depletion of the high-grade Lake ores, Warren District, Republic Steel Corporation, have used up to 40% of New York State magnetite ores in the manufacture of basic iron. The titanium dioxide present limits to 15% of the burden its use for making Bessemer iron.—E. J. B.

Copper-Bearing Cast Iron. B. Vécsey. (Bányászati és Kohászati Lapok, 1950, vol. 5, Dec. ; Öntöde, 1950, vol. 1, Dec., pp. 271–276). [In Hungarian]. The author reports on Hungarian experiments to produce copper-bearing grey iron in a small blast-furnace using burnt pyrites as a raw material. The chemical composition of the pig iron obtained and the test data, composition, and micrographs of the specimens are also given. The properties of the iron obtained were very satisfactory. The source of copper for making this iron was a by-product from Hungarian sulphuric acid plants.—E. G.

Reorganisation and Reconstruction of Blast-Furnace Plant at the Works of Park Gate Iron and Steel Company, Limited. T. Bishop. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 9, pp. 299–304). The modernization of the blast-furnace plant at the works of Park Gate Iron and Steel Co., Ltd., is outlined. Wagon tippers, conveyor belts, bunkers, scale cars, and fully automatic charging gear have replaced hand skip-charging and hand-operated distribution, and the pig beds have been superseded by a pig-casting machine. Output has increased by about 20% with a considerable reduction in manpower.—G. F.

Mechanization of the Charging Blast-Furnaces. T. Sawicki. (Przeglad Techniczny, 1951, Feb., pp. 73–81). [In Polish]. The problem of automatic charging of blast-furnaces is discussed and a short description of some modern installations is given.—V. G.

PRODUCTION OF STEEL

Steelworks 'Brandenburg,' Technical Progress. H. König. (Die Technik, 1950, vol. 5, Dec., pp. 574–576). A brief description is given of the first steelworks built in the East German Republic according to new plans. The furnaces have been running for only two months, and at 60% capacity because only one pouring crane is available. The layout of the new works, comprising ten open-hearth furnaces, departs from the pre-war one, in that the axis of the plant is parallel to the waterway, and three scrap stockyards are provided—two adjacent to the end furnaces, and the third facing the middle four furnaces and separating the two sets of gas producers. The latter have been placed as close to the furnaces as possible in order to minimize tar deposition in the gas mains.—J. G. W.

Assessment of Materials Economy in the Basic-Bessemer Process by Heat-Balance Calculations. E. Senfter, G. Schnürch, and H. Guthmann. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 334–343). The drawing up of a heat balance for the basic-Bessemer process from thermodynamic data allows defects in operation to be discovered, addition agents to be evaluated and the effect of constructional changes to be assessed. The greatest value of a heat balance lies in the continuous control of materials economy and thus in the possibility of making effective use of excess heat. Nomograms, derived from results of laboratory experiments, are given for determining the heat evolved in the oxidation of dissolved phosphorus, silicon, carbon, and manganese, and for calculating the lime requirements and the excess heat when blowing different qualities of pig iron with various excess amounts of lime of different qualities.—J. P.

The Production of Low-Phosphorus, Low-Nitrogen Steels Using Heat-Generating Agents. H. Höfges and J. Willems. (Stahl und Eisen, 1951, vol. 71, Mar. 15, pp. 283–287). Low-nitrogen, low-phosphorus steels can be made in the Bessemer converter by cooling the metal just before the end of the carbon period by additions of ore, but the metal so produced is frequently too cold for good casting. This disadvantage can be overcome by adding calcium–silicon alloy and allowing the oxidation thereof to heat the metal. In this way special mild steels have been made with very low impurity content and properties similar to those of open-hearth heats. A low-nitrogen, low-phosphorus metal prepared in this manner for alloying in the electric furnace has brought about considerable increase in output. Estimations have shown the usual relationship between oxygen in the metal and FeO in the slag, and indicated that the FeO distribution coefficient is a function of the P_2O_5 content of the slag.—J. P.

Manufacture and Properties of Low-Nitrogen Basic-Bessemer Steel. P. Coheur, J. Daubersy, L. Marbais, M. Nepper, and L. Dor. (Revue Universelle des Mines, 1950, vol. 6, Dec., pp. 401–430). After a short review of past work and a discussion of the importance of low-nitrogen steel the paper is divided into four parts. In Part I Coheur reports on an investigation into the use of an oxygenated blast and fluxes containing variable amounts of chalk and compares the results with those obtained in normal practice. He concludes that with this technique it is possible to reduce the nitrogen content by 30–35% to less than 40 parts in 10,000, *i.e.*, less than an average open-hearth steel. In Part II Daubersy gives experimental details of the use of a water-vapour/oxygen blast. Using this blast, steels containing less than 20 parts of nitrogen in 10,000 have successfully been produced. In Part III Marbais and Nepper give the results of physical and mechanical tests which have been used in these investigations to assess the quality of the low-nitrogen steels produced. They confirm that the reduction of the nitrogen content leads to improved production of wire, strip, and sheet steel. In Part IV Nepper and Dor make a full statistical study of the results and give details not only of the conclusions which may be drawn from this investigation but also of the statistical methods employed.—B. G. B.

Trends in Steel Plant Controls for Quality. H. J. Forsyth. (Blast Furnace and Steel Plant, 1951, vol. 39, Jan., pp. 69–73). In the U.S.A. control of production and quality is being extended by statistical analysis, instrumentation, and chemical research. In the blast-furnace the development of top gas analyses enables thermal shifts to be predicted. In the Bessemer converter 92% removal of sulphur has been effected by adding 300–400 lb. of sodium hydroxide to 14 short tons of metal. The use of the immersion pyrometer in

the open-hearth furnace of one works has reduced skulling by 50% and the number of sticker ingots by 40%. The loss of manganese by oxidation during tapping was reduced from 2·38 lb. to 0·82 lb./ton by using a tilted ladle. Spectroscopic analysis saved 20 min. per heat in one electric furnace shop. E. J. B.

Basic Steelmaking : A Survey of the Physical Chemistry of Sulphur. C. E. A. Shanahan. (Iron and Steel, 1950, vol. 23, June, pp. 279–283 ; July, pp. 313–316). In this review the author first deals briefly with the concepts of activity and free energy, and discusses the variation of the activity of sulphur in iron with composition. The structure of slags is considered, and the mechanism of sulphur removal by basic slags is described using the ionic conception of slag structure. The importance of slag basicity and empirical formulæ used in its calculation are discussed. Finally, the author outlines the conclusions of some of the numerous experimental investigations made on sulphur migration from metal to slag, and considers the behaviour of gaseous sulphur on slag/metal systems.—G. F.

Rapid Desulphurisation : Treatment of Open-Hearth Metal with Liquid Slag. A. Gimenez y Sanmartin. (Asociacion Nacional de Ingenerios Industriales : Iron and Steel, 1950, vol. 23, Aug., pp. 352–354). The author gives brief details of trials of a rapid open-hearth steel desulphurization process which involves mixing the steel with a liquid slag in the ladle. A fixed 25-ton basic furnace is used, the liquid slag being made in a 6-ton basic arc furnace together with a 5-ton charge of steel of the same specification. A white fluid slag is desired, the quantity being 3½% of the total quantity of steel. The electric furnace slag and steel are tapped into the ladle, and after removing the open-hearth slag, the main charge is tapped into the same ladle. In twelve successive casts, the sulphur content was decreased by an average of 42%, whilst the phosphorus, silicon, and manganese contents were sometimes increased and sometimes decreased. Typical slag analyses before and after mixing are included. The author considers that the steel is superior to normal open-hearth steel, and that the process has distinct possibilities in works in which a suitable liquid slag can be made.—G. F.

The Effect of Carbon on the Activity of Sulphur in Liquid Iron. J. P. Morris and R. C. Buehl. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 317–322 ; Journal of Metals, 1950, Feb.). A description is given of a study of the equilibrium conditions in the following reaction occurring between hydrogen gas and dilute solutions of sulphur in liquid iron–carbon alloys : $S_{(liquid)} + H_{2(gas)} = H_2S_{(gas)}$. The carbon content of the metal is shown to have a marked influence on the equilibrium conditions ; at constant temperature and constant H_2S concentration in the gas phase, the sulphur content of the metal at equilibrium decreases as the carbon content increases. At 1600° C. and with 2·3% C in the metal, the activity coefficient of sulphur is twice that for sulphur dissolved in pure iron, and at carbon saturation it is more than six times as great. The effect of temperature on the reaction is shown to be small. At 4·35% C, the relationship between the equilibrium constant K and temperature T may be expressed as : $\log K = -450/T - 1·74$.—G. F.

Thermodynamic Properties of Sulphur in Molten Iron–Sulphur Alloys. C. W. Sherman, H. I. Elvander, and J. Chipman. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 334–340 ; Journal of Metals, 1950, Feb.). A description is given of an investigation into the thermodynamic properties of sulphur dissolved in liquid steel, a study being made, over the temperature range 1530–1730° C. with sulphur concentrations up to 4·8%, of the equilibrium in the reaction : $H_{2(gas)} + S_{(liquid)} = H_2S_{(gas)}$. The free-energy change in this reaction has been established as a function of temperature, and values of the activity coefficient of sulphur have been determined. The effect of silicon on the activity coefficient of sulphur is computed from the data of Morris and Williams, and it is shown that these data and those of White and Skelly, on the same reaction ; are in good agreement with the results of the present investigation.—G. F.

A Method of Measurement of Interphase Tension. S. I. Popel', O. S. Esin, and P. V. Gel'd. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 74, No. 6, pp. 1097–1100). [In Russian]. The method and apparatus for the measurement of interphase tension between liquid metals and slags are described.—V. G.

Interphase Tension at the Boundary of Iron Alloys and Slags. S. I. Popel', O. A. Esin, and P. V. Gel'd. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 75, No. 2, pp. 227–230). [In Russian]. The interphase tension at the boundary of iron and slag was measured. The influence of silicon and carbon content of iron and slag composition on this tension was investigated.—V. G.

The Slag Diagram of Technical Iron and Steel Making Processes. E. Witten. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 138–146). The results in the literature on slag–metal equilibria have been examined and the following conclusions reached. The CaO/SiO_2 ratio of basic and acid slags and temperature determine uniquely the slag structure, particularly the iron and manganese contents thereof. The slag takes up as much iron and manganese from the metal bath as are necessary to liquify its CaO–SiO_2 basic mixture. Alumina and magnesia can reduce appreciably the melting point of the slag and thus lead to a lowering of the iron and manganese contents. Iron and manganese liquify the slag, the ratio of iron to manganese depending on the residual manganese content of the metal. A slag diagram has been developed which shows the iron and manganese contents over the whole basicity range. Just above the melting point of the slag, the compounds of CaO with SiO_2 and iron, and of manganese with SiO_2 are stable. Overheating of the slag tends to decomposition of a part of these compounds and the return of iron and manganese to the metal. The slag composition thus becomes such that its melting point is just below the actual temperature. In the case where the melting point of the basic CaO–SiO_2–Al_2O_3–MgO mixture coincides with the actual slag temperature, the slag will pick up only little iron or manganese ; it can be heated above its melting point and then possesses good desulphurizing power. This emphasizes the importance of slags in the basicity range 40–55, since they offer the prospect of an advantageous desulphurization in the cupola and the Bessemer converter.—J. P.

The Electrical Resistivity of Titanium Slags. J. L. Wyatt. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 989–994 ; Journal of Metals, 1950, Aug.). The specific electrical resistivities of titanium-containing slags, with iron oxide contents ranging from 2% to 30%, are reported. The resistivity values are shown to be a definite function of the FeO content but, contrary to the results of other investigations, they are not greatly affected by temperature. In comparison with siliceous slags, titanium slags have an extremely low electrical resistivity, and thus electric furnaces for smelting titaniferous iron ores must be specially designed in order to achieve the best results.

The Manganese Equilibrium under Simple Oxide Slags. J. Chipman, J. B. Gero, and T. B. Winkler. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 341–345 ; Journal of Metals, 1950, Feb.). New experimental data are presented on the manganese equilibrium in liquid steel under simple slags consisting of oxides of iron and manganese with small amounts of impurities. The values of the equilibrium constant K_{Mn} obtained are significantly lower than those of Körber and Oelsen, and generally higher than those of other investigators. The experimental data agree fairly well with results of thermodynamic calculation from published data obtained at lower temperatures. The distribution of oxygen between the slags and liquid metal is found to conform to the solubility curve of Taylor and Chipman.—G. F.

The Use of Radiocalcium to Study the Distribution of Calcium between Molten Slags and Iron Saturated with Carbon. W. O. Philbrook, K. M. Goldman, and M. M. Helzel. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 361–367 ; Journal of Metals, 1950, Feb.). A description is given of an investigation in which radioactive calcium was used to determine whether calcium could be detected in iron saturated with carbon, after melting under CaO–Al_2O_3–SiO_2 slags similar to blast-furnace slags. No calcium could be detected in the iron under conditions which favoured reduction of calcium, and the authors conclude that the calcium content of the iron was less than 6×10^{-5}%, and that no direct reaction between calcium and sulphur dissolved in molten iron can contribute significantly to desulphurization in the blast-furnace.—G. F.

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The Solubility of Oxygen in Liquid Iron Containing Aluminium. D. C. Hilty and W. Crafts. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 414–424; Journal of Metals, 1950, Feb.). Using a rotating crucible induction furnace and an experimental technique involving close temperature control and rapidly quenched samples, the authors have determined the solubility of oxygen in liquid iron containing aluminium at 1550°, 1600°, and 1650° C. The results obtained are much greater than those calculated theoretically, and the authors consider that this difference may be due to the metal phase being in equilibrium with an iron–aluminium spinel phase rather than with pure solid Al_2O_3 as assumed in the calculations. The presence of manganese greatly increases the deoxidizing power of aluminium, whilst the presence of silicon appears to have no significant effect.—G. F.

Solubility of Oxygen in Liquid Iron Containing Silicon and Manganese. D. C. Hilty and W. Crafts. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 425–436; Journal of Metals, 1950, Feb.). The authors describe determinations of the solubility of oxygen in liquid iron containing silicon and/or manganese. In the case of silicon, the oxygen solubility is found to agree well with that reported by Körber and Oelsen, whilst manganese is shown to be 50–70% more effective in limiting the oxygen solubility than was previously considered from the work of Körber and Oelsen. In combination, silicon and manganese are shown to be substantially more effective than either element individually. A graph is presented comparing the deoxidizing abilities at 1600° C. of manganese, silicon, and aluminium, individually and in combination.—G. F.

Flow of Fluids at High Temperatures: Research to Aid Steel-Furnace Technology. M. P. Newby. (Iron and Coal Trades Review, 1951, vol. 162, Apr. 6, pp. 779–785). The author describes model work in progress at the B.I.S.R.A. Physics Laboratories concerning the flow of fluids at high temperatures, methods of controlling the flow, and the action of hot fluids on refractories. The work includes a study of the movement of the blast-furnace burden under the action of the blast, an investigation of the mixing conditions in open-hearth furnaces, and determinations of flow patterns in converters and open-hearth furnaces. Experiments inside newly built furnaces before firing are also mentioned. The value of the results of the model work and their application to the design and operation of furnaces are discussed.—G. F.

Production Costs of Ingots Produced in Open-Hearth Furnaces with a Limestone Charge. A. E. Dobner. (Hutnické Listy, 1950, vol. 5, Dec., pp. 495–500). [In Czech]. The author deals with the costs incurred by the consumption of limestone and other slag-forming components, and refractory materials in steelworks working with charges containing 52% and 65 to 80% of pig iron. Production costs per ton of ingot are expressed in 'standard' costs (planned) and 'actual' costs. The operational economy can be gauged by comparing the 'actual' with the planned 'standard' ones.—E. G.

Research into the Deoxidation of Open-Hearth Mild Steel. M. Nepper and H. Herbiet. (Revue Universelle des Mines, 1951, vol. 7, Feb., pp. 56–70). Many different physical and chemical methods have been employed in an investigation of eight casts of open-hearth mild steels obtained from four different steelworks. The authors have tried to assess the quality of these samples with particular reference to the internal macroscopic properties and to relate this quality with the process of deoxidation. The results obtained enable an estimate of the possible improvements in quality as a result of deoxidation to be made. The relative values of the different methods of oxygen analysis used in these investigations are reported.—B. G. B.

Metal Composition Tests for the Steel Melter. H. H. Fairfield, H. F. Graham, and A. E. McMeekin. (Canadian Metals, 1950, vol. 13, Nov., pp. 18–21, 40–41). Hardenability properties of steels are shown to be suitable for rapid prediction tests of tensile strength during melting, speed being desirable in view of high operating costs of electric furnaces. Machined bar, as-cast, and reheated cast hardenability were tried and the as-cast test found sufficiently accurate for control purposes. It could be carried out by the melter, enabling him to compensate for residual alloys. Carbon was determined by means of Rockwell A hardness tests on pin-shaped, fully hardened, and 100% martensitic samples of cast steels in a range of 0·10 to 0·45% carbon.—E. C.

Some Tests on Decarburization by Means of Oxygen in a 2-Ton Electric Arc Furnace. L. Piana. (Metallurgia Italiana, 1951, vol. 43, Jan., pp. 20–26). Details of oxygen decarburization tests are given together with data on the experimental technique. Destructible burners and non-destructible burners with refractory nozzles were tried as well as the introduction of oxygen through the furnace electrodes. Details are given of the results obtained after prolonged testing. The economics of the process are discussed and the factors which lead to the adoption of oxygen decarburization in current production are reviewed.—M. D. J. B.

Practical Aspects of Tool Steel Melting. C. F. Sawyer, jun. (Journal of Metals, 1950, vol. 188, Dec., pp. 1433–1434). The author briefly discusses some of the practical aspects of tool steel melting in the basic electric arc furnace, dealing with the composition and placing of the charge, melting and refining procedure, and casting practice.—G. F.

Today's Scrap—Availability, Condition and Contamination. R. W. Farley and R. J. McCurdy. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, 1950; Journal of Metals, 1950, vol. 188, Dec., pp. 1435–1438). The authors discuss the availability of scrap for electric furnaces in the light of present-day world events, and point out some of the specific requirements of the scrap supply and possible improvements in meeting these requirements. The sources of scrap are considered, and the condition and size of scrap and correct charging are discussed. Contamination of scrap is dealt with.—G. F.

Deoxidizing in the Ladle with Carbortam. W. O. Igelman and D. A. Finch. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, 1950: Journal of Metals, 1950, vol. 188, Dec., pp. 1439–1441). The authors describe the changes made in the acid electric furnace melting and refining procedure in the production of steel for castings, when 'Carbortam' was substituted for aluminium as a deoxidizing agent. The use of 'Carbortam' increased the ductility of the steel and eliminated many tempering treatments, and also increased the fluidity and greatly reduced the number of chain-type inclusions. The most suitable steelmaking procedure when using 'Carbortam' is detailed.—G. F.

Slag Control in the Basic Electric Arc Furnace during Production of Cast Steel and the Effect on Production Economy. W. Trommer. (Neue Giesserei, 1950, vol. 37, June 29, pp. 249–255). An account is given of trials performed to increase the recovery of chromium from the charge, without prolonging the duration of the heat, and maintaining acceptable phosphorus values. Recovery factors ranging between 60 and 85% were obtained without affecting dephosphorization.

J. G. W.

The Deoxidation Properties of Vanadium. A. Horváth. (Kohászati Lapok, 1951, vol. 6, Jan., pp. 20–24). [In Hungarian]. The deoxidation properties of vanadium are dealt with on the basis of results of research work published by Chipman and by Samarin and Polyakov. The Russian experimental work was carried out in a 50-kg. high-frequency furnace. The charge consisted of scrap iron containing 0·05% C, 0·35% Mn, 0·025% S, 0·020% P, and traces of silicon. Ferrosilicon and ferrovanadium were added. Results are reported and compared with those of Chipman. Samarin and Polyakov conclude that: (1) If equal percentages of vanadium and silicon are present in the liquid steel, the latter will retard the oxidation of vanadium, which has its full oxidizing properties only if the silicon content drops below 0·1%; (2) in the fluid slag the vanadium is present in the form of $FeO.V_2O_3$; at 1600, 1650, and 1700° C. vanadium has a lower deoxidizing effect than silicon at the same temperatures.—E. G.

Increase of Ingot Mold Life *versus* Surface Quality of Billets. L. A. Boldizar. (Blast Furnace and Steel Plant, 1951, vol. 39, Jan., pp. 74–77). At J. A. Roebling's Sons Co. works 9-in. squares of $\frac{1}{16}$-in. plywood placed across the bottom of their 15 in. by 15 in. big-end-up ingot moulds reduced the cutting of the plug area and increased the average ingot life from 46·2 to 89·8 casts. The surface quality of billets was increased by 4·2% and the proportion of scrapped billets decreased from 2·1% to 1·2%.—E. J. B.

Casting Defects Caused by Core Gases. H. L. Campbell. (Foundry, 1950, vol. 78, June, pp. 86–87, 210, 212–213). The production of cavities in castings by core gases and possible means to reduce these are discussed.—E. J. D. S.

FOUNDRY PRACTICE

Foundry Scrap, with Particular Reference to the Question of Raw Materials. E. Feil. (Neue Giesserei, 1950, vol. 37, Aug. 10, pp. 313–320). The kinds of scrap in the foundry and the causes of bad castings are described. Evidence bearing on the 'inheritance of scrapping characteristics' through the remelting of faulty castings is presented and remedies are suggested.—J. G. W.

Pig Iron in the Iron Foundry. C. W. Pfannenschmidt. (Neue Giesserei, 1950, vol. 37, Mar. 23, pp. 105–113). Reviewing the development in Germany of the production and use of foundry pig iron, the author shows that the occurrence of casting defects has been more frequent during certain periods, apparently connected with difference of blast-furnace practice, the quality of pig iron produced depending among other things on the rate of driving of the furnace. Even after remelting in the cupola, certain characteristics of the pig iron, in particular coarseness of structure and amount of combined carbon, are normally reproduced in the casting. Recent research on the effect of blast-furnace working conditions on pig-iron composition and quality, and on the 'inheritance' by the casting of the properties of the pig iron, are reviewed; the inheritance is not yet fully understood. Methods of reducing or eliminating it are the use of a high remelting temperature, particularly by using a hot-blast cupola, and inoculation. Various future possibilities involving the after-treatment of pig iron in heated mixers are suggested. H. R. M.

Gases in Pig Iron and Their Influence on the Quality of Raw Materials and Castings. V. Zednik. (Hutnické Listy, 1950, vol. 5, Nov., pp. 445–449, Dec., pp. 485–495). [In Czech]. The author reviews the present knowledge on the influence of gases in pig iron on the quality of castings and describes experiments carried out on this subject at the Vitkovice steelworks. The gas contents of hematite pig iron from Hungarian blast-furnaces and from Czech and foreign pig irons were determined and the influence of remelting on the gas content, graphitization, and structure was investigated. Metallographic, chemical, and spectrum analyses were also made in the case of most of the raw materials. The chemical compositions and the gas contents of the individual pig irons are given, as well as the hydrogen, oxygen, and nitrogen contents of the material at the various stages of remelting in a cupola and a high-frequency furnace. Pictures of the microstructure and fractures of specimens are included. The author emphasizes that there is a contradiction between the relation of the oxygen solubility in iron and the temperature and the thermodynamic equilibrium of oxidation. Investigation revealed considerable differences in the gas contents even in the case of specimens taken at successive intervals from the same melt. Older samples had high gas contents which were probably due to the absorption activity of graphitic carbon. Both laboratory and works tests showed that remelting has a favourable influence on gas content. The most serious difficulties occur in the case of ferritic iron and irons with a tendency to overcooling, but very frequently gas content is blamed instead of incorrect inoculation. A hydrogen content of 2 cu. m./100 g., considered critical by Riley for castings high in silicon, is, according to the author, not critical in the case of grey-iron castings.—E. G.

Determination of Contents of Foundry Ladle during Pouring. P. Sahmel and H. Pieper. (Neue Giesserei, 1950, vol. 37, June 1, pp. 211–213). The weight of metal may be calculated from the degree of tilt of the ladle, if the dimensions of the latter are known. The authors develop the necessary formulæ, provide tables for certain standard dimensions of a ladle, and show in a photograph the method of attaching a scale graduated in weight units.—J. G. W.

Metallurgical Research Problems and Their Application to Foundry Practice. W. Oelsen. (Neue Giesserei, 1950, vol. 37, May 18, pp. 185–189). Recent progress in the physical chemistry of steelmaking is reviewed and the relevance of the problems studied to foundry practice is considered. The topics discussed are: Solubility of slag oxides as a function of the reactions taking place; desulphurization by blast-furnace slags of various basicities and its use in the cupola; and the principles of dephosphorization.—J. G. W.

Foundry Technical Control: Correlation of Production Variants with Performance in Service. (Iron and Steel, 1950, vol. 23, Dec., pp. 491–495). A brief outline is given of the manufacture of ingot moulds at the foundry of Distington Engineering Co., Ltd., and of the system of correlating mould performance with production variables. This system is of the nature of a large-scale statistical operation requiring a very large number of cases to be taken into consideration, and necessitates the recording of full details of both the manufacture and the usage of each mould.—G. F.

Fundamental Considerations on the Degassing of Liquid Metal Baths. W. Geller. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 57–63). Dissolved gases can be removed from molten metals by three methods, *viz.*, formation of insoluble stable solids, liquids or gases by addition of suitable agents; reduction of the gaseous partial pressure above the melt; and flushing out with another gas. The theoretical laws governing degassing by flushing and their consequences are discussed at length. The type of gas solution plays a very important part; thus if the Sievert square root law applies, degassing is more difficult than if solubility is directly proportional to pressure. The possibility of using a flushing gas instead of vacuum distillation for the separation of metals is referred to. The applicability of the theoretical laws is illustrated by results of model experiments and of removal of nitrogen during the boil in open-hearth and electric arc furnaces.—J. P.

The Induction Cupola at Aachen. E. Piwowarsky. (Neue Giesserei, 1950, vol. 37, Sept. 7, pp. 357–359). An induction-heated hearth has been fitted to the experimental cupola at the Technische Hochschule, Aachen. The heating coils are of water-cooled copper tubing and are fed from the mains at 380 V., 50 cycles/sec. The construction of the heater and some results on the rate of heat input to an iron charge are described.—J. P.

Dimensions and Performance of Cupolas. K. Roesch and K. Guthmann. (Neue Giesserei, 1950, vol. 37, Mar. 9, pp. 85–92). A questionnaire circulated to German foundries brought in replies giving particulars of 520 cupolas. This paper analyses the replies to show how the following quantities are related in present practice to cupola diameter: Furnace output, weight and height of charge; tuyere size; and blast air flow and pressure. The present practice with regard to coke consumption, coke quality, height of the initial coke charge, flue gas composition, the temperatures of the blast, flue gas, tuyere zone and molten iron, and amount of limestone used, is also discussed. A distinction is drawn between grey cast iron and malleable iron practice and where necessary different grey irons are considered separately. The information presented is finally summarized in tabular form for cupola diameters between 400 and 1400 mm.—H. R. M.

Melting with Oxygen-Enriched Air in the Cupola. H. Jungbluth. (Neue Giesserei, 1950, vol. 37, Sept. 21, pp. 382–387). Theoretical considerations predict that, as compared with cold air blast in the cupola, the use of oxygen-enriched air should result in increased output, higher iron and lower top-gas temperatures, and a decrease in loss of iron and manganese by burning, when the comparison is made at equal coke rates and blast volumes. The operational data so far available confirm this prediction. Comparison of costs indicates that such a mode of operation is not outside the bounds of economic possibility and should repay further trials. Hot blast operation is similar to that with oxygen-enriched air; output, at equal coke rates and blast volumes, is not so great.—J. P.

Problems of Mechanical and Thermal Design of the Hot-Blast Cupola. O. Günther. (Die Giesserei, 1950, vol. 51, June 1, pp. 205–209). The author bases his paper on many years' practical experience in running hot-blast cupolas. He is of the opinion that this cupola type has passed the test of industrial utility and yields remarkable fuel economies for medium and large melting capacities. The article contains a brief history of the development of the hot-blast melting method, constructional and thermal data of the blast-heating plant, information on measuring and control instruments, maintenance, blast temperatures, and the problem of dust. A table of particulars of five different cupolas is included and the shortcomings of the cold-blast type are discussed.—J. G. W.

A New Type of Cupola. R. Doat. (Italian Metallurgical Association: Foundry, 1950, vol. 78, Nov., pp. 172, 174–176). The hot-blast cupola known as the 'Metallurgical Blast Cupola' and the process are described; *see* Journ. I. and S.I., 1951, vol. 167, Feb., p. 216.—R. A. R.

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Prerequisites for the Production of Hot Cupola Iron and the Advantages of an Effective Coke Coating. E. Piwowarsky and H. Eyckeler. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 181–185). Experiments with a small cupola have shown that the use of increased blast volumes raises the temperature of the hot zone of the cupola and results in hotter metal. The concomitant higher coke consumption can be cut down by coating the coke with high melting Portland or aluminous cement, which does not allow the coke to react till it reaches the hot zone. In this way, the temperature of the cupola can be raised by 100–300° C. By coupling this procedure with the use of heated blast, good results are to be expected in respect of coke consumption, iron temperature, and the production of high-grade cast iron. A lower current consumption in the arc furnace is also to be expected when the metal is treated by the duplex process.—J. P.

Profits from Nodular Iron. B. Dixon. (Canadian Metals, 1950, vol. 13, Nov., pp. 14–16, 43). From experience in production of nodular iron castings the author stresses the need for operational experience with alloy irons, and for close control of composition of cupola charge, melting procedure, and inoculation. Correct understanding and appreciation of the special properties of nodular irons are necessary for commercial production and best use in view of relatively high costs.—E. C.

Status, Development, and Future of Nodular Grey Cast Iron. E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 175–180). Although the development in America and Britain of nodular cast iron represents a marked advance in foundry technique, it is claimed that the developments in Germany during the last two decades have shown how to produce ductile high-strength cast irons without resort to deliberate addition of magnesium or cerium.—J. P.

Some Experiences with a Low-Nickel Magnesium Alloy for the Production of Nodular Cast Iron. W. Patterson. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 195–197). Experiments have shown that it is possible, with a comparatively low-nickel Mg–Si–Ni alloy, to produce nodular cast irons with properties identical with those of irons produced with the more usual Mg–Ni alloys. Tests have already shown that magnesium alloys, free from heavy metal, can be used economically for the same purpose. J. P.

A Complete Structural Diagram for the Production of High-Duty Cast Iron. H. U. Doliwa. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 3, June, pp. 119–123). An attempt is made by means of simple thermodynamic calculations to find an explanation for the scatter of tensile and hardness values of cast iron, particularly for alloys which are nearly saturated with carbon. After the importance of cooling conditions has been proved, a method is indicated for the construction of a diagram which will allow for all material factors such as chemical composition, wall thickness, overheating, and mould material. From hardness measurements on cast wedges, lines of equal hardness as a function of degree of saturation and wall thickness, have been determined. A comparison of 30-mm. test bars of cupola and electric furnace iron have confirmed the fact that cupola iron is softer; this is attributed to the action of CO_2 which induces the iron to solidify grey.—J. P.

The Production of Nodular Cast Iron by Treatment with Magnesium Alloys. E. Piwowarsky, K. Krämer, W. Patterson, and M. Krichel. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 3, June, pp. 91–103). The earlier uses of magnesium alloys in the foundry and the development of nodular cast iron are reviewed. Investigations have been conducted to ascertain the most suitable way to produce nodular castings, and certain technological recommendations are made. The theory of the formation of spheroidal graphite is discussed.—J. P.

Practical Experiences in Producing Nodular Cast Iron. M. M. Hallett. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Jan. 4, pp. 3–12, 16). The two recognized methods, the cerium process and the magnesium process for producing nodular cast irons are described, and the influence of alloying elements mentioned. Regarding its founding characteristics, the metal has good fluidity, despite its sluggish appearance, but tends to chill in thinner sections. Its greater shrinkage over normal grey irons necessitate more attention to satisfactory feeding techniques. Such irons fill the gap existing between high-duty grey-iron and steel castings, and are likely to be complementary, rather than competitive, with malleable irons.—J. E. W.

Nodular Cast Iron. H. Morrogh. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 65–74). The production and properties of nodular cast iron, as developed by the British Cast Iron Research Association, and described elsewhere (*see* Journ. I. and S.I., 1947, vol. 155, Mar., pp. 321–371 and 1948, vol. 158, Mar., pp. 306–322) are reviewed.—J. P.

Gaseous Annealing of Whiteheart Malleable Iron. F. Schulte. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 47–56). The literature on the subject of reducing the carbon content of cast iron by annealing in gaseous atmospheres is reviewed. The particular metallurgical advantages of the process are the improved uniformity of temperature, greater freedom in the use of cooling or after treatments, and freedom from peeling. The special properties of different types of gas atmosphere are described and the advantages of steam or air–steam mixtures are explained. A new operational procedure is described, in which the composition of the annealing atmosphere is automatically maintained at the correct composition by using some of the exit gases to boil water to produce steam for feeding into the gas stream and so maintain a correct oxygen potential. The calorific value of the exit gases falls as decarburizing proceeds and thus the amount of steam is automatically adjusted.—J. P.

Some Design Rules for Steel Castings. H. Resow. (Neue Giesserei, 1950, vol. 37, Oct. 5, pp. 444–448). Steel castings should be of the simplest shape and free from marked variation in wall-thickness if trouble from stresses, cracks, and cavities is to be avoided. Shrinkage is more pronounced with steel than with cast iron and although the amount can be assessed on standard pieces, results on practical castings often deviate from expected behaviour. Obtaining correct final dimensions depends on close collaboration between the founder and the designer.—J. P.

Manufacture of Cast Steel Rolls. S. R. Robinson. (Foundry, 1950, vol. 78, Dec., pp. 188, 190, and 192). Recommended compositions for steel rolls and hints on the foundry practice are presented, together with a suitable annealing cycle. Nodular iron is expected to compete with cast steel as a roll material.—E. J. D. S.

Good Steel Casting Design Improves Quality and Reduces Costs. C. W. Briggs. (Materials and Methods, 1951, vol. 33, Feb., pp. 68–71). The low fluidity of liquid steel, the low strength and high shrinkage on solidification, and the high cooling stresses, are inherent characteristics which must be understood and considered when designing castings. Methods of preventing 'hot spots,' the choice of safety factors, and the effect of variations in section thickness are briefly reviewed.—P. M. C.

The Production of 12% Manganese Steel Castings. F. Roll. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 147–160). The results are reported of a series of experiments on 12% manganese steel castings, designed to supply information to the foundry. They concern the effect of heat-treatment on bend strength and deflection at break, tensile strength and extension, toughness, shear strength, hardness, and work hardenability. The influence of annealing temperature on the hardness of the various phases and carbide solution processes, and the effect of Mn/C ratio on carbide solution rates are shown diagrammatically. J. P.

On the Impact Strength of Bessemer Steel Castings. E. Piwowarsky and W. Wüllenweber. (Neue Giesserei, 1950, vol. 37, July 27, pp. 293–296). The Bessemer process is the most attractive of all steelmaking processes from the point of view of cast-steel production, for the capital cost of the equipment is small, the process is quick, and the steel (on account of its high temperature) is particularly suitable for the manufacture of thin-walled castings. The widespread objection to Bessemer steel castings on account of the alleged low impact strength is only partly justified. By reference to their own and other researches the authors show that satisfactory impact strength may be achieved by limiting the carbon content to 0·35% max.; reducing the phosphorus and sulphur contents of the casting; minimizing the oxygen

and nitrogen contents; and by high-temperature diffusion annealing followed by quenching and tempering. The authors conclude that these ideas are fully exploited by large foundries in Germany and abroad, but are largely unknown in the small foundries.—J. G. W.

The Croning Process for Moulds and Cores. H. N. Acker. (Canadian Metals, 1950, vol. 14, Feb., pp. 30, 31, 46). The Croning method of making moulds with a mixture of sand and a thermosetting resin is described and illustrated. [This process has been described by B. N. Ames, S. B. Donner, and N. A. Kahn; *see* Journ. I. and S.I., 1951, vol. 168, May, p. 97].

Recent Progress in the Cement Sand Moulding Process. M. Beilhack. (Neue Giesserei, 1950, vol. 37, July 27, pp. 296–300). This process, which improves the quality of castings, simplifies moulding, reduces costs, and makes smaller demands on the moulder's skill, is gaining popularity in Germany and abroad. The plant and the procedure are described and its application illustrated by numerous examples.—J. G. W.

A New Measuring Quantity in the Testing of Moulding Sands. W. Reitmeister. (Neue Giesserei, 1950, vol. 37, June 15, pp. 225–231). The author proposes the use of a new quantity for comparing different sands. This is the 'specific form volume' obtained as follows: 1 kg. of sand is placed in a container 6 cm. in dia. and compacted in a hand-operated machine of the author's design by means of 800 blows, each raising and dropping the container 1 cm. The quantity varies with moisture content in a similar manner to porosity and likewise passes through a maximum. The use of this 'specific form volume' in conjunction with measurements of grain size is illustrated for a number of different sands.
J. G. W.

Ohio's Mineral Resources. IV—Foundry Sand. D. C. Williams. (Ohio State University Studies, 1950, vol. 19, Nov., Engineering Experiment Station Circular No. 53). Extensive data are presented on the particle size distribution and chemical composition of a large number of Ohio foundry sands. Experimental work is described which shows that the mulling operation can produce grain fragmentation.
R. A. R.

The Problem of Core-Bonding Materials. Gy. Szváth. (Kohászati Lapok, 1951, vol. 6, Jan.; Öntöde, 1951, vol. 2, Jan., pp. 13–15). [In Hungarian]. The problem of core-bonding materials has not yet been solved in Hungary. The compositions and physical properties of various core mixtures used in Hungary are described.—E. G.

Surface Tension of Liquid Metals. D. V. Atterton and T. P. Hoar. (Nature, 1951, vol. 167, Apr. 14, p. 602). Experimental values of surface tension for liquid metals are found to be inversely proportional to atomic volumes. This enables surface tension to be empirically determined from density measurements, and indicates that metal penetration of sand in castings is dependent on the reciprocal of the atomic weight only.—A. G.

Physical Principles of Consolidation of Binding Agents. K. Würzner. (Chemie, Ingenieur, Technik, 1950, vol. 22, Aug. 28, pp. 348–351). The author holds that consolidation of binders depends on physical processes consequent upon capillary forces, chemical reactions exerting additional influences. Relevant literature is surveyed in brief, and processes are described which are involved in the setting of clays, gypsum, and Portland cement. The possible influences of molecular forces of adsorption and cohesion are discussed.

The Effect of Different Methods of Compressing Sand on the Quality of Moulds for Grey Iron. V. Frey. (Dissertation: Eidgenössischen Technischen Hochschule, Zürich, 1950). A modified form of the DVM method of sand testing has been developed in which the ramming work is varied by increasing the number of blows and simultaneously reducing the ram weight to 2 kg. Sands of different densities can be tested and a 'sand characteristic' diagram drawn up. The compressive strength is used as the basis of comparison for different sands. Means of obtaining more uniform density and less scatter in test data on sand specimens are described. An optimum moisture content at which gas permeability is at a maximum was observed. A 'ramming density measurer' is described. The uniformity of the sand density was equally good at optimum moisture content using either the jolt-squeeze machine or the sandslinger. Moulds rammed with a compressed air tool were less uniform.—R. A. R.

New Sand Testing Apparatus. W. H. Moore. (Foundry Trade Journal, 1951, vol. 90, Jan. 11, pp. 46–49). A new approach to the problem of sand control is given. The emphasis of control is placed on developing strength in the sand body, to withstand rupturing forces, rather than on reducing the rupturing forces to the point where they do not exceed the strength characteristics of the sand. After pointing out that the usual high-temperature tests do not conform with practice, the author's method is detailed. The sample is maintained at the desired temperature, and then raised above the furnace, where it is fractured by a transverse impact blow. The energy required to fracture the sample is taken as a measure of the toughness. The advantages in using this method of testing are given.—J. E. W.

Experimental Work on Oil Sand Practice. D. T. Kershaw. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Feb. 1, pp. 115–122). Curves given show that maximum green strength, using a cereal binder, is obtained with 1–2% water; that the addition of linseed oil reduces the green strength progressively, though the incorporation of red sand increases the green strength at the expense of permeability. Referring to the baked sand, the deleterious effect of red sand is shown. A linseed oil and cereal bonded sand is best baked for 2 hr. at 200° C., but the substitution of 40% aromatic extracts for the linseed permits of greater flexibility, and the advantages of adding 1% ammonium nitrate are also illustrated. Other curves relate gas content with the substitution of used sand, and show the effect of used sand on strength, and the effect of core temperature on the compression strength.—J. E. W.

Pouring Time and Its Relation to the Solution of Gating Systems. J. Kieswetter. (Hutnické Listy, 1951, vol. 6, Jan., pp. 14–22). [In Czech]. A mathematical analysis of the flow of the liquid metal into the mould is presented. The purpose is to derive formulæ for the pouring times and the design of gating systems. The analysis is based on hydrodynamic laws and the derived relations have been confirmed by experimental and full-scale data. The formula is suitable for calculating the pouring times as a function of the wall thickness and weight of the casting, and a coefficient taking into consideration the filling speed of the mould. This formula differs considerably from the one proposed by H. W. Dietert in 1930. A table is included which contains numerical values of pouring times for grey-iron castings weighing between 10 kg. and 40 tons, with wall thicknesses of 3 to 55 mm. Further tests are necessary to check the validity of the formula for castings of very large sizes and unusual shape.—E. G.

Running and Feeding of Castings. H. S. Farmer. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Apr. 5, pp. 357–362). The requirements of a runner system and a feeder head are defined. Methods of conforming to such requirements by means of controlling the pouring temperature, the thermal properties of the sand, and the correct positioning of ingates and feeder heads are given. Reference to the work of Briggs; Jazwinski, Wells and Finch; and Williams in obtaining the maximum efficiency from feeders is made. The correct use of chills, and of such chill-inducing media as tellurium, and insulation material having a gypsum base are discussed. Finally, various standard runner systems, such as trap runners, strainer cores, bottom, step, and top runners, whirlgates, and the 'lip feeder' or 'Conner' runner are illustrated.—J. E. W.

Drying of Foundry Moulds and Cores. G. T. Hampton and W. H. Taylor. (Institute of Fuel: Foundry Trade Journal, 1951, vol. 90, Feb. 15, pp. 169–175). Various types of equipment for drying new sand, cores, and moulds are reviewed. The relative merits of static and rotary sand dryers, old and modern battery stoves and continuous core ovens for drying cores; and stove drying, hot air drying, and torch drying for moulds, are compared. Figures are given for the fuel used per ton of sand dried, and the relative costs.—J. E. W.

Intricate Castings from a Durable Loam Mould. J. Currie. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Apr. 12, pp. 383–388; Apr. 19, pp. 419–425). A description is given of the making of a semi-permanent loam mould for a large evaporator body, weighing nearly 7 tons, over 7 ft. long, 6 ft. wide, and of 1 in. average section. Four castings were produced after which the mould was completely dismantled and rebuilt to produce further castings.

The mould was split into three parts vertically, and five parts horizontally, only two being used during moulding, the other joints being made in order to remove the casting. The method of gating was designed so as not to impede the removal of the mould sections after casting.—J. E. W.

Manufacture of Ingot Moulds for an Indian Steelworks. V. M. McGowan. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, Apr. 19 ; pp. 411–416). The three problems to be faced were : (1) The prevention of cracking due to casting strains ; (2) to obtain the best possible iron composition, hematite iron being too costly ; and (3) to find the correct pouring temperature. The cores were made on a coreplate, which was also the bottom box, and consisted of three main parts : the bottom plate, a core bar, located in the bottom plate, and a retaining plate, which was attached to the core bar, and was pinned to the main plate by two countersunk cotters. The bar could easily be removed after casting, thus relieving all casting strain. The moulding, and the drying of mould and core are described. Running was effected by four drop runners placed one on each side of the mould. Casting was effected at a temperature of 1220° C. and the metal composition was total carbon, 3·2% ; Si, 1·7–1·8% ; Mn, 0·68–0·75% ; P, 0·28–0·32% ; S, 0·07–0·08 ; G. C, 2·9%. The average life of the moulds including those scrapped in the foundry was 66·23 casts.—J. E. W.

Compressed Air Moulding Machines—Simple and Jolt-Ramming Lifting and Turnover Types. B. Gebhardt. (Neue Giesserei, 1950, vol. 37, Sept. 21, pp. 397–405). **Compressed Air Moulding Machines in the Foundry.** B. Gebhardt. (Metalen, 1950, vol. 5, Oct., pp. 36–39). A general illustrated review deals with air compressors and their control, and simple moulding machines. The advantages and disadvantages of lifting and turnover types are discussed and typical examples are described.—J. P.

The Production of Spun Cast Iron Pipes. W. J. Ayre. (Institute of Australian Foundrymen : Australasian Engineer, 1951, Feb. 7, pp. 59–63). The author describes the complete process of pipe manufacture at Australian Iron and Steel Limited, Port Kembla, N.S.W. Two cupolas of 96 in. shell diameter and 16 tons/hr. melting capacity supply four horizontal-mould casting machines. Pipes may be cast to either 4, 6, 8, or 20 in. dia. After annealing, each pipe is hydrostatically tested, and then lined with cement or tar.—P. M. C.

Centrifugal Casting in Engine Construction. H. Lüttger. (Neue Giesserei, 1950, vol. 37, May 4, pp. 165–167). The author describes briefly modern centrifugal casting methods and devotes particular attention to their application to cylinder liners for internal combustion engines.—J. G. W.

Precision Casting by the Lost-Wax Process. K. Zimmermann. (Neue Giesserei, 1950, vol. 37, Mar. 23, pp. 113–115). Modern developments in precision investment casting, in which Germany has up to the present played no part, are reviewed, with reference chiefly to American publications.—H. R. M.

Trends in the Development of Material for Grey-Iron Piston Rings. C. Englisch. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 165–170). Three ways are being adopted to produce high-performance piston rings. These are : (1) Use of a material with a comparatively low Young's modulus ; a thick wall and large compression when fitting enables a considerable pressure to be exerted on the cylinder wall without overstraining the ring. (2) Refining the graphite and reducing grain size so as to obtain a high Young's modulus. A compromise must be reached between good wall pressure and wear behaviour. (3) Use of hard chromium-plated rings. The iron can then be chosen for optimum elastic properties without regard to wear in service.
J. P.

Straight Cast-Iron Pipes. J. L. Handley. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, Mar. 15, pp. 275–280). The methods employed in the moulding and casting of straight cast-iron pipes are described. The pipes described are segregated under three headings : (1) Soil and ventilation pipes. (2) Vertically cast pressure pipes. (3) Centrifugally cast pipes. A typical metal composition is C 3·2–3·5%, Si 1·8–2·2%, P 1·0% max., Mn 0·35% max., and sulphur as low as possible. Manganese in excess of 0·35% produces 'pimpling' on the insides, the pimples being extremely difficult to remove.—J. E. W.

Investment Castings—Their Design and Limitations. D. F. B. Tedds. (Engineer, 1951, vol. 191, Mar. 2, pp. 292–294). The author describes the investment casting process for shapes and alloys that are difficult to form by other production methods. The advantages and commercial limitations of the process are examined. Design considerations for producing precision castings, castings of thin cross-section and large surface area and castings of heavier section by gravity casting techniques are reviewed. Design factors are considered together with the process limitations, surfaces finishes, soundness, warpage, and tolerances. Costs are also dealt with.—M. D. J. B.

Growth of an Idea. W. G. Gude. (Foundry, 1950, vol. 78, June, pp. 88–93). The growth and operation of a foundry producing 50 tons of castings for agricultural equipment per day is described.—E. J. D. S.

Mechanized Bath-Tub Foundry of Diepenbrock and Reigers N.V. at Ulft. (Metalen, 1950, vol. 5, Oct., pp. 31–35). [In Dutch]. The layout of this modern Dutch foundry, the treatment of moulds, patterns and cores, and the cleaning and enamelling of the baths are described.—R. S.

Pianoforte Frame Castings. (Foundry Trade Journal, 1951, vol. 90, Feb. 22, pp. 199–204). At the iron foundry of the Mildmay Ironworks of Booth and Brookes, Ltd., metal is provided by two hand-charged cupolas, 7 to 8 tons/day being melted. Most moulds are made on the floor and are cast in the green state. Pattern plates are preferred to loose patterns, a novel feature being the production of 'utility' plates. After casting the piano frames localized heating and stripping prevent distortion. Cast-in 'dimples' eliminate the use of jigs for drilling the frames. Subsequent treatment consists in stoving for 4 hr. at 180° C., rubbing down with emery cloth, spraying with bronze powder in a cellulose medium, and the final application of two coats of clear cellulose varnish.—J. E. W.

Roll Manufacture at the Whifflet Foundry of R. B. Tennent, Limited, Coatbridge. D. D. Howat. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 16, pp. 383–385). The history and recent expansion of the Whifflet foundry of R. B. Tennent, Ltd., Coatbridge, are briefly described, and details of the works and of the manufacture of chilled iron and steel rolls are given. Casting techniques and the subsequent heat-treatment and machining of the rolls are considered, and brief details of the melting furnaces and foundry layout are given. The foundry is capable of producing the heaviest type of cast rolls, of 35–45 tons finished weight.—G. F.

Continuous Production in the Foundry Industry. F. Fischer. (Neue Giesserei, 1950, vol. 37, June 1, pp. 218–221). The author describes a highly mechanized foundry with reference to layout drawings and photographs of conveyor-belt sections of the plant.—J. G. W.

Foundry Conditions in Great Britain. J. W. Gardom. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, Feb. 8, pp. 153–156 ; Feb. 15, pp. 183–186). Attention is drawn to the shortage of skilled labour ; serious efforts must be made to attract youths to the industry. Adequate apprentice training, small foundries combining in this respect, and the development of two Craft Training Centres on a national basis are mentioned. The British Foundry School aims to supply technicians and managers, and provide refresher courses for foremen. The two Government reports on working conditions have stimulated the industry's efforts in this respect.—J. E. W.

The Use of Compressed Air in Foundries—Its Production and Cost. F. Imberger. (Neue Giesserei, 1950, vol. 37, Sept. 21, pp. 391–397). After mentioning the uses of compressed air in the foundry, the methods of production and distribution, as well as leakage, are discussed. The effect of the type of compressor and its regulation on cost are indicated.—J. P.

Foundry Organisation : Operations at a Repetition, Semi-Mass-Production Foundry. (Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 369–372). A description is given of the operation of the repetition foundry at the works of R. J. Hunt and Son, Ltd., which produces a wide range of castings up to 65 lb. in weight. As the castings do not lend themselves to full mechanization, high production is maintained by maximum loading of the moulding floor with mechanically aided supplies, and synchronization of the other operations.
G. F.

Mechanization and Rationalization of Foundry Operations. E. Piwowarsky. (Neue Giesserei, 1950, vol. 37, Sept. 21, pp. 388–391). The methods by which foundry operations may be mechanized and efficiency improved are discussed with particular reference to those adopted in the U.S.A.—J. P.

Safety and Hygiene in the Foundry. J. Steele. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, Jan. 11, pp. 41–45). The appointment of a safety engineer, an assistant, and two inspectors, to ensure the safe working of 8500 employees, the establishment of a central safety committee, and a modern casualty centre are described. Desirable architectural features and layout are detailed, and the undesirable effects of coal and coke fires are mentioned. Adequate protective clothing will mitigate against burns, and the provision of safe pouring platforms is advised. Means for preventing accidents with mills, cranes, and in turning-over operations are described.—J. E. W.

Safety in a Foundry. F. S. Harper and R. E. Hurnall. (Institute of Australian Foundrymen : Australasian Engineer, 1951, Jan. 8, pp. 92–95 ; Feb.. 7, pp. 44–47). In the first part of this article the authors discuss general principles of accident prevention, and outline accepted methods of accident investigation and report. Part II shows how the general principles may be applied to a foundry.—P. M. C.

Theoretical and Technical Training of Apprentices, Foremen, and Engineers in the Foundry Industry. E. Hugo. (Neue Giesserei, 1950, vol. 37, Sept. 21, pp. 405–412). The activities of the Education Committee of the Verein Deutscher Giessereifachleute are summarized.—J. P.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Improvements in Furnaces and Methods for Heat Treatment. F. E. Harris. (Metal Progress, 1951, vol. 59, Jan., pp. 63–68). This review of advances in the past decade, first considers the heating process and then deals with improvements in high-temperature recirculating fans, and the increased use of radiant-tube heating. However, the greatest progress has been in the use of furnace atmospheres. There follows a brief consideration of endothermic generators and carburization. E. T. L.

Which Process for Case-Hardening Steel—Carburizing, Nitriding or Carbonitriding ? K. Rose. (Materials and Methods, 1951, vol. 33, Feb., pp. 62–64). The main features (including cost, type of plant, and field of use) of the following processes are outlined : Pack, liquid, and gaseous carburizing ; nitriding ; liquid cyaniding ; and gaseous carbonitriding.—P. M. C.

How to Cut Heat-Treat Costs. R. F. Kern. (Machinist, 1950, vol. 94, Sept. 2, pp. 1278–1283). The planning and installation of an efficient gear heat-treating department at the Springfield Works of the Allis-Chalmers Co. is described. The following points are considered : (1) Analysis of general heat-treating practices ; (2) determination of the heat-treating equipment required, by studying all gear drawings in order to schedule each part into either continuous or pit-type carburizing furnaces ; (3) scientific shop layout ; (4) close control of (*a*) heat-treating operations, (*b*) dimensional quality, (*c*) carburizing quality, (*d*) quenching practice, and (*e*) fuel utilization ; and (5) a preventive maintenance programme consisting of (*a*) scheduled shut-downs for internal inspection and replacement of parts before complete failure, (*b*) regular burning out of carbon deposit to preserve heat-resistant alloy furnace parts and provide for closer atmosphere control, and (*c*) stocking a full set of spare parts as recommended by the manufacturer.—E. C. S.

Steel Castings : A Review of the Literature on Homogenisation. A. Hartley. (Iron and Steel, 1950, vol. 23, Dec., pp. 511–514). The author concludes that, when homogenization is followed by the usual heat-treatment, the benefits derived are negligible. Homogenizing castings for 12 hr. at temperatures up to 1232° C., followed by the usual heat-treatment, has no appreciable effect on tensile strength, ductility, impact value, hardenability, and microstructure, although partial or complete diffusion of the as-cast dendritic structure may occur. In certain steels, homogenized for 80 hr. at 1280° C., there is a pronounced decrease in hardenability. Calculations suggest that removal of microsegregation of carbon may take place, but macrosegregates are not affected to any appreciable extent.—G. F.

High-Speed Steel : Some Developments in Heat Treatments. H. Carr. (Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 383–388). The author describes how marked improvements in the performance of tools made from steels of standard compositions can be effected by modification of heat-treatment. The high-speed steels considered have the following compositions : (1) 18% W, 4% Cr, 1% V ; (2) 14% W, 4% Cr, 4% V ; and (3) 18% W, 4% Cr, 1% V, 5% Co. The author gives the correct procedures to be adopted in isothermal annealing, preheating and high-heating, quenching, and tempering, and also mentions various surface treatments used.—G. F.

Distortion of Tool Steel in Heat Treatment. J. Y. Riedel. (Metal Progress, 1950, vol. 58, Dec., pp. 853–859). Distortion consists of (*a*) warpage and (*b*) volume change (such as occurs on hardening, and transformation to austenite). It is impossible to calculate the first in the case of water-quenching. The effect of shape on volume-change distortion inherent in heat-treating, is discussed, and also the effects of scaling, variation of quenching, tempering, and rehardening of steel. Details are given of the heat-treatment of high-carbon, high-chromium steel to give no distortion in one direction. Practical rules for the control of the distortion are given for the two cases where there is little or considerable grinding to be done after hardening.—E. T. L.

Blanking Dies : Heat Treatment of High-Carbon, High-Chromium Steels. J. R. Bryant. (Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 411–413). The effects of various hardening and tempering treatments on two 10% Cr, 2% C die steels, one containing 3% Co, are described. It is shown that the steels require adequate soaking at the hardening temperature if full hardness is to be developed, the hardness values decreasing fairly uniformly with increase in tempering temperature. The utmost precautions must be taken to prevent decarburization.—G. F.

Austempering. K. Walz. (Die Technik, 1950, vol. 5, Dec., pp. 581–585). The author gives a general description of the austempering treatment with particular reference to the properties of the quenched material. Having explained what austempering is and pointed out the difference between austempering, patenting, and hot-bath quenching, the author states that views about the effect of austempering on the mechanical properties are not unanimous, but that in general it is agreed that it gives better Izod values and greater elongations in the tensile test for the same hardness, provided the latter is above Rockwell C 35. Better fatigue strength is also reported. The author concludes by giving a list of steels suitable for the austempering treatment, and outlines a typical plant and operation.—J. G. W.

The Oxy-Acetylene Flame-Hardening of Tyres. S. V. Begun. (Avtogennoe Delo, 1949, No. 1, p. 26). [In Russian]. In the compact apparatus described, wheels whose rims are to be hardened are rotated on a shaft while an oxy-acetylene flame and a jet of water play on the rim.—S. K.

Electronic Control of Production Flamatic Hardening. M. Garvin and D. Strauchen. (Welding Journal, 1950, vol. 29, Nov., pp. 981–985). New developments are described for producing flame-hardening parts. These include electronic temperature control of the surface and depth control of hardening by proper combination of variables.—U. E.

Flame-Hardening of the Surface of Cast Iron. H. W. Grönegress. (Stahl und Eisen, 1951, vol. 71, Mar. 1, pp. 246–252). The development and present position of flame-hardening of cast iron is discussed. In order to obtain maximum hardness and resistance to wear, the iron should have at least 0·5% combined carbon and the graphite finely distributed. Meehanite and nodular iron are suitable materials for the purpose. Blackheart malleable iron can be surface flame-hardened and then shows a high damping capacity and a fatigue strength as high as that of steel. The practical applications of surface-hardened cast iron include guides of machine-tool beds, crank- and camshafts, cylinder liners, bearing rings, and deep-drawing and pressing dies. J. P.

Liquid Flame Hardening Used to Selectively Harden Steel Gear Teeth. T. C. Du Mond. (Materials and Methods, 1951, vol. 33, Jan., pp. 74, 75). A new method for selectively hardening gear teeth has been developed by the Yale and Towne Mfg. Co. (U.S.A.). The gears (four at a time on a horizontal shaft) are rotated at 45 r.p.m. with the teeth just submerged in the surface of a salt bath held at the required hardening temperature. Quenching in oil at 150° F. completes the treatment, and the gears are free from scale and unwanted distortion.—P. M. C.

Using Oxyacetylene to Reduce Stress. H. E. Kennedy. (International Acetylene Association : Canadian Metals, 1950,

vol. 13, Nov., pp. 36–38). Residual stresses in welded structures are discussed, also conditions under which failure may occur. Simple methods of heat-treatment are advocated as effective preventive measures, results obtained with test specimens being quoted in support.—E. C.

Carbon Restoration Overcomes 'Soft Skin' on Parts. E. C. Bishop. (Machinist, 1950, vol. 94, Dec. 16, pp. 1805–1812). The decarburized surface of steel parts and tools, found to have a soft skin, can be restored to the original carbon content by batch or continuous heat-treatment. Fully automatic generators of suitable furnace atmospheres carry out the process. Dew point, which is the key to successful control, is easily measured and recorded. Suitable atmospheres are produced from Westinghouse Electric Corporation's "Monogas" (0–15% H_2, 1·0–2% H_2O, 0–12% CO, 5–12% CO_2, 0–1·5% CH_4, balance N_2) or "Endogas" (36–40% H_2, 0·10–2·00% H_2O, 18–20% CO, 0·0–1·0% CO_2, 0·0–1·5% CH_4, balance N_2) by adjusting the dew point to approximately −40° F. and the CO_2 content to 0·02–0·05%.—E. C. S.

Gas Carburization. S. C. Churchill. (Machinery, 1950, vol. 77, Aug. 10, pp. 172–175). The author outlines a process which essentially consists of compressing raw town's gas and passing it to a catalytic furnace to produce a mixture, of which rather less than half the volume is made up of CO_2 and CH_4 in roughly equal proportions, the remainder being chiefly hydrogen with 4–5% nitrogen. The methods of case-hardening low-carbon steels are also dealt with.—E. C. S.

Gas Carburizing Bearing Races. (Machinery, 1950, vol. 77, Aug. 24, pp. 234–235). A gas-fired, pit-type, gas-carburizing furnace, employing U-shaped recuperative radiant tubes as the heating elements has been designed and constructed by Birlec, Ltd., Birmingham, and recently installed by British Timken, Ltd., at their Aston works. A description of it is given.—E. C. S.

Production Case Hardener. W. L. Corteggiano. (Machine Design, 1950, vol. 22, July, pp. 125–127). The case-hardening of cylindrical parts, $\frac{3}{8}$–2 in. in dia. and $1\frac{3}{4}$–18 in. long, by induction heating on the Westinghouse horizontal rotating scanner is described.—E. C. S.

The Induction Heat-Treatment of Weld Seams of Carbon Steel. V. V. Aleksandrov and T. A. Vashchurova. (Avtogennoe Delo, 1949, No. 8, pp. 20–23). [In Russian]. An account is given of experiments made to find the best conditions for the induction heat-treatment of butt-welded low-carbon steel plates 15, 34, and 50 mm. thick. The best results were obtained with rapid heating followed by cooling in air.—S. K.

Nitriding Tool Steels: Procedures and Results. J. G. Morrison. (American Society of Tool Engineers: Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 376–378). The procedures used in the nitriding of high-speed tool steels, and the properties to be expected are briefly discussed, and some practical applications of nitrided tool steels are given. Results of impact and bend tests and microhardness determinations on various high-speed steels in the as-nitrided condition and in the stress-relieved condition after nitriding show no significant difference between the two conditions, but stress-relief reduces the tendency to minute spalling of the cutting edge when regrinding.—G. F.

Bright Hardening, Carburizing and Carbonitriding. H. Ipsen and R. Krogh. (Metal Progress, 1951, vol. 59, Feb., pp. 232–238). This deals with controlled-atmosphere heat-treatments, for surface finishing. Gas-flow control now prevents sooting, and the use of various organic gases prevents oxidation. These interrelated factors are explained, and a table is given of the conditions for successful heat-treatments. Practical details of the furnace, and costs are considered.

E. T. L.

Carbonitriding in Present Practice. W. H. Holcroft. (Metal Progress, 1950, vol. 58, Dec., pp. 843–846). Carbonitriding is divided into three classes, for work requiring shallow case-hardening, work subject to excessive distortion in heating and liquid quenching, and work needing a hard surface and an annealed core, respectively. The first of these is most common, and is here dealt with. There is a brief discussion of the effects of temperature and quenching media, and of suitable furnaces. Ammonia or nitrogen in the furnace atmosphere does not affect its carburizing action, except by dilution. However, nitrogen in austenite increases the proportion of retained austenite on quenching, and so causes some decrease in hardness. The amount of nitrogen in solution is enhanced by too much ammonia in the atmosphere, and lessened by the use of higher temperatures in the furnace.

Use of Oxyacetylene Process to Reduce Stress. H. E. Kennedy. (Welding Journal, 1950, vol. 29, Nov., pp. 985–988). Several methods for reducing stresses are discussed. In practice, welding stresses of 40,000 or 45,000 lb./sq. in. may be reduced to negligible values by running oxy-acetylene torches on either side of the weld at such a speed that the plate metal is raised to 350°. The heated area should be 6 in. wide. The operation is accomplished at about 18 in./min.

U. E.

Spheroidization and Decomposition of Carbides (Graphitization) during Annealing of Silicon Steel. S. Z. Bokshtein. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 2, pp. 311–314). [In Russian]. The spheroidization and decomposition processes of carbides during annealing (at 550–700° C.) of silicon steels (C 0·4%, Si 0·25%, 1·75%, and 2·75%) were investigated by means of X-ray, metallographic, and carbide analyses.—V. G.

The Tempering of Steels and Metallurgical Variables. E. D. Bia. (Institute of Materials Testing of the Engineering Faculty of Montevideo, Uruguay, Publication No. 21, 1950, vol. 4, May, pp. 1–16). [In Spanish]. An open-hearth steel (C 0·564%, Si 0·208%, Mn 0·556%, P 0·013%, S 0·016%) was hardened in an electric furnace at 825° C. and water-quenched, at temperatures up to 700° C. The structural changes are described and the relationships between hardness and tempering cycles and between resistance to strain and structure are considered.—R. S.

The Effect of Isothermal Treatment on the Mechanical Properties of Steel. M. D. Jepson. (Metallurgia, 1951, vol. 43, Feb., pp. 62–64, 81–82). Comparison is made between isothermally transformed material (tempered in some cases) and quenched and tempered specimens. The results show the isothermal treatment to have an advantage, but the marked inferiority exhibited by the quenched samples tempered at temperatures below 300° C. was found to be due to embrittlement by the molten solder of the tempering bath.—J. B. B.

FORGING, STAMPING, DRAWING, AND PRESSING

Designing Low-Cost Forgings. J. J. Sloan and K. R. Denny. (Machine Design, 1950, vol. 22, Aug., pp. 154–156). Given equal costs, die forgings are generally preferred to castings or extrusions because of their high strength/weight ratio. A table of these ratios is included. The nature of the forging process is such that it shapes the grain of the metal into approximately the direction required by design. Some design considerations for die forgings are: (1) Where grain direction is critical it should be specified on the drawing: (2) place the parting line to minimize machine time both on die and part; (3) draft of 7° is required, one of 5° and backdrafts are subject to the approval of the die suppliers; and (4) for corner radii, fillet radii, and tolerances on die forgings use Drop Forging Association Standards.—E. C. S.

De Roll Semi-Automatic Precision Forging Machine. (Machinery, 1950, vol. 77, Sept. 14, pp. 300–301). This machine, developed by the Société des Usine de Louis de Roll, S.A., Switzerland, although primarily designed to forge parallel cylindrical workpieces to close limits of accuracy, can also pre-form grooved articles such as splined shafts, twist drills and reamers, also triangular, four-sided, and tapered workpieces, by using additional equipment which is available. Hot cylindrical workpieces may be formed to limits of accuracy of + 0·008 to + 0·016 in. on diameter and, by employing a second cold-forging operation, the work can be reduced in size to leave only 0·004 in. for the finishing operation. The English agents are Lancing Machine Tools, Ltd., Commerce Way, Lancing, Sussex.—E. C. S.

Advances in Heavy Closed Die Forging. E. O. Dixon. (Steel Processing, 1951, vol. 37, Feb., pp. 63–68, 101). The author discusses in general terms the progress made during the last decade in the size, quality, and economy of the closed die forging method of metal forming. Details are given of the construction and performance of a German counter-blow hammer which is now operating at the Ladish Co. (U.S.A.). This hammer, in which tup and anvil move towards each other, is equivalent in forging performance to a conventional hammer of estimated rating of 100,000 lb. Necessary improvements in furnaces and die blocks, in order to work a hammer of this size, are discussed.—P. M. C.

Faster Forging. J. M. Kelly. (Iron and Steel, 1950, vol. 23, July, pp. 333–336 ; Aug., pp. 363–366 ; Sept.–Oct.–Nov., pp. 413–414). The author discusses the attainment of the fastest possible production in a stamp shop. He considers the shop layout and plant, the movement of materials, and problems of engineering, maintenance, and labour. Suggested layouts of forges are included. He next considers the various controls necessary to ensure continuity of production, dealing with die design, process planning, production control and recording, supply and control of materials, and liaison with the customer. Examples of control wall-boards for both planning and controlling production are given.—G. F.

Improved Dies for the Cutlery Industry. (Metal Treatment and Drop Forging, 1951, vol. 18, Feb., pp. 71–74). The manufacture of cutlery involves the forging of stainless steel which, although easy to work at the appropriate temperature, is very hard on the dies. The article discusses the preparation and use of die blocks made from a proprietary steel which has substantially increased die life. The steel is 'Diehard,' and it contains 1·5–2·0% C, 12–13% Cr, and small amounts of molybdenum and vanadium. Stages in the production of dessert and carving knives up to the final trimming are described, and mention is made of the forging machinery employed.—P. M. C.

Impact Stamping Comes of Age. P. Brenton. (Steel Processing, 1951, vol. 37, Feb., pp. 69–73). The economics, uses, and operation of this process are discussed, its main feature being that the dies are made from fairly soft non-ferrous metals and alloys (lead, aluminium–zinc, lead–antimony). These dies are about one-tenth as costly as steel dies, are easily cast and shaped, and can be salvaged for recasting. This means that short runs on sample parts can be made without the expense of steel tooling.—P. M. C.

Stamping Die Sets and Relative Equipment. J. E. Hyler. (Steel Processing, 1951, vol. 37, Feb., pp. 74–78). The author reviews die storage, checking, and repair procedures, and describes several die-handling machines. The Moore 'Die Flipper' is described in detail and illustrated.—P. M. C.

Flexibility in a Press Shop. R. Le Grand. (Machinist, 1950, vol. 94, Oct. 7, pp. 1429–1436). Flexibility in a press shop is obtained by efficient stock handling from the time it is received until finished parts or sub-assemblies leave the plant. Methods and equipment for producing blanks should be versatile and economical. Attention must be paid to adequate room for work in progress. How presses are mounted, their accessibility for service, and ease of rearrangement when products change are explained. Effective use of presses is related to their ability to accept dies with little or no modifications and the press room must be supported by tool and die-making facilities capable of making prompt repairs and producing new tools as required. The author shows how the Chrysler Corporation has taken these and other matters into consideration at their Nine Mile press plant, near Detroit. E. C. S.

Reducing Process Makes Precision Tubing. H. E. Linsley. (Machinist, 1950, vol. 94, Dec. 2, pp. 1746–1747). Production of accurate internal shapes and precision, straight or tapered tubing is possible by the compression-reduction process which also improves the mechanical properties of hot-finished material. The inside diameter can be held to a total tolerance of 0·005 in. In the process performed by the Tube Reducing Corp., the work is passed between a pair of curved oscillating dies and is indexed one-sixth of a turn at each stroke. The increase in hardness is not merely a skin effect, but exists throughout the metal. The process is fast and enables stocks of unwanted large tubing to be used by having them reduced to some wanted size.—E. C. S.

The Production of 20-Pounder Shells. (Engineering, 1951, vol. 171, May 11, pp. 573–574). A description is given of the manufacture of 20-pounder shells at the Royal Ordnance Factory at Wigan. The reorganization of the factory and the production sequence are described in detail. A feature of the works is an extensive conveyor system designed so that the shells follow a fixed route. The various machining processes are divided into a large number of simple operations, none requiring complicated tooling arrangements or special knowledge.—M. D. J. B.

Improving the Quality of Drawing Tools by Controlling Die Profile by Modern Measuring Methods. W. Lueg. (Stahl und Eisen, 1951, vol. 71, Feb. 15, pp. 157–167). The importance of optical and recording profilometers for controlling die shapes is illustrated by measurements on carbide and diamond dies for round and special-section steel wires.—J. P.

ROLLING-MILL PRACTICE

A Report of Rolling Experiences. L. Moses. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 59–65). This paper gives considerable information on rolling-mill practice, rolling speeds, and roll design. Maximum speeds are discussed and the relation between roughing and finished delivery speeds is considered. The author suggests that the roughening proclivities would be lessened if the time passage of a given arc of contact could be increased ; alternatively by enlarging the volume of roughing-roll bodies, the better to conduct away applied bar heat. Examples are given showing roll profiles, projected contact areas, and other details of roll design. The information given is based on practical experience supported by scientific considerations.—M. D. J. B.

Rolling Mills : Design and Provision of Finishing Equipment. J. R. Cuthbert and M. S. Doshi. (Iron and Steel, 1950, vol. 23, Nov. 28, pp. 416–420). The authors discuss the design and provision of finishing equipment required to process the rolled material before dispatch and sale, the causes of the curving of rolled material being described and illustrated. The finishing equipment considered comprises hot saw and shears, cooling banks, roller straightening machines, gag presses, and loading arrangements. The theory of straightening is also outlined.—G. F.

Nomograms for the Evaluation of Hitchcock's Formula for Roll Flattening. D. A. Winton. (Sheet Metal Industries, 1951, vol. 28, Jan., pp. 16, 17). Hitchcock's formula is rewritten in the form :

$$R' = R\left[1 + \frac{2CP}{\delta}\right]$$

in which R' and R are the radii of the deformed and undeformed arcs of contact, P is the roll force per unit width of rolled material, δ is the draft, and C is a constant depending on the roll material. A nomogram of the 'grid' type, in which R' and P are the vertical ordinates and R and δ are the grid lines, is developed for use with both steel and cast-iron rolls. Values of R' are easily obtained when the other three variables are known.—P. M. C.

Metal Flow, Elongation, and Spread in Regular Sections. Z. Wusatowski and A. Wojtylak. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 23–46). [In Polish]. An attempt is made to establish a theoretical basis for quantitative determination of metal flow during the rolling of regular sections. The results of the authors' calculations when compared with those obtained in practice during rolling showed good agreement.—V. G.

Plant Manufacture for the Iron and Steel Industry by Lamberton and Company, Limited (Coatbridge). (Iron and Coal Trades Review, 1951, vol. 162, Feb. 23, pp. 447–448). The Coatbridge works of Lamberton and Co., Ltd., is engaged in the manufacture of plant for the iron and steel industry, including rolling mills and their auxiliary equipment, and a complete range of forge plant. A brief history of the firm is given, followed by a description of the works and its equipment.—G. F.

The Present Situation in the Construction of Rolling Mills at Home and Abroad. T. Dahl. (Stahl und Eisen, 1951, vol. 71, Mar. 1, pp. 229–244). Methods of construction and operation of modern rolling mills for strip and tubes in Germany and elsewhere, particularly U.S.A., are described. Future developments aim at increasing production and thus reducing labour costs and improving surface quality and strip uniformity. Consideration of the number of modern mills being built in other parts of Europe indicates that West German plant is out-of-date and requires to be modernized if Germany is to retain her competitive position as a steel producer.—J. P.

Rolling Mills : Current American Research, Design, and Installations. A. I. Nussbaum. (Iron and Steel, 1950, vol. 23, Dec., pp. 481–486 ; 1951, vol. 24, Jan., pp. 11–15 ; Feb., pp. 55–58). In Part I, the author briefly discusses current American research into the rolling process. Part 2 is concerned with American methods of mill design. In Part 3 the author reviews the latest trends in American rolling-mill installations, and describes examples of the following types of mill : Blooming and slabbing ; plate ; rail and structural ; billet, bar, and rod ; hot-strip ; tube-rolling ; cold-rolling ;

and single-stand reversing. Finally, in Part 4 the author describes some of the ancillary equipment associated with these mills.—G. F.

Electricity in Rolling Mills: Part 1—A Survey of Current Practice; Part 2—A.C. Auxiliary Drives; Part 3—Direct Current Drives; Part 4—Rolling-Mill Drives. F. L. Parkin. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 23, pp. 427–432; Mar. 2, pp. 499–506; Mar. 9, pp. 553–559; Mar. 16, pp. 615–622; Mar. 23, pp. 665–670). These articles enumerate the leading electrical applications on modern rolling mills and explain some of the problems arising. A survey of current practice is made in Part 1, in which the supply and distribution of A.C. and D.C. power, power plant, and power and load factors are discussed. Part 2 deals with A.C. auxiliary drives, with particular reference to the choice and application of small- or medium-sized motors and their associated starting and control equipment, whilst Part 3 gives similar consideration to D.C. drives, with special attention to overhead crane equipment. The use of direct current in energizing lifting magnets is also described. Finally, drives for cogging and slabbing mills, billet mills, strip and bar mills, cold-rolling mills, and small hand bar mills are discussed in Part 4, together with controllers and auxiliary equipment.—G. F.

Factors Determining the Choice of Electrical Equipment for Steel Rolling Mills. N. R. D. Gurney. (Sheet Metal Industries, 1951, vol. 28, Feb., pp. 117–134). This is a comprehensive survey of the factors determining the choice of motors for different types of mill. The relative merits of induction, synchronous, and D.C. motors are outlined, and the motors and drives required for typical reversing mills, wide hot and cold strip mills, and merchant bar and rod mills are described.

P. M. C.

Ventilation of Steel Mill Motors and Motor Rooms. S. L. Jameson. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 68–72). The different types of ventilating systems for mill motors are described; recirculating and non-recirculating systems are considered in detail and their effect on carbon dust and humidity discussed. Three types of air filter for use in steel-mill ventilation are also described, namely the travelling screen oil film filter, the air washer, and the electrical precipitation filter.—M. D. J. B.

Automatic Control of Various Operations in the Iron and Steel Industry. A. B. Chelyustkin and B. A. Levitanskiy. (Promyshlennaya Energetika: Bányászati és Kohászati Lapok, 1950, vol. 5, Dec., pp. 700–704). [In Hungarian]. The problems of automatic controls and the automatic operation of rolling mills in the U.S.S.R. are discussed. The principles of operation of control and detection apparatus for rolling mills, designed by the Soviet Central Laboratory for Automatic Controls, are briefly described.—E. G.

The Design of Grooves in Pilger Rolls. W. Scheurer. (Stahl und Eisen, 1951, vol. 71, Mar. 15, pp. 299–300). An alternative method is proposed by which to calculate the shape of grooves in Pilger rolls. The method is presented in the form of a series of curves showing the relationship between wall thickness of the bloom and finished tube and the length of the base of the groove.—J. P.

The Blooming Mill—Steel Industry's Iron Horse. R. H. Wright. (Iron and Steel Engineer, 1951, vol. 23, Mar., pp. 98–105). A review is given of the early methods of reducing ingots. The relatively unchanged design in blooming mills is attributed to the soundness of the original design. Steam-operated blooming and slabbing mills are described together with the developments of the electric motor which led to the beginning of the electrification of the steel industry in the U.S.A. in 1916. The problems in the development of mill motors are discussed. Finally, features of present-day reversing mills are reviewed; these include dynamic braking for bringing the flywheel set to rest, and oil lift for the flywheel bearings to prevent damage to the bearings when starting after a prolonged shut-down.—M. D. J. B.

Modern Blooming Mill Practices. D. W. Lloyd. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 59–64). This paper discusses the problem of determining the source of surface defects and their control. These sources have been divided into four groups: (1) Open-hearth furnace, (2) soaking pits, (3) rolling mill and (4) conditioning yard. The effect of open-hearth deoxidation practice and casting-pit practice is discussed in connection with the formation of surface defects and sub-surface defects. Poor practices in soaking pits and reheating and the effect such practices have on the finished product are also discussed. Rolling-mill defects such as overfills, underfills, laps, scratches, and shearing, necessitating conditioning in the semi-finished state are examined, and the methods used in the conditioning yard for their removal are described.—M. D. J. B.

Sources of Defects in Rolling. P. Grüner and T. Brüggemann. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 20–28; Jan. 18, pp. 71–77). The sources of many of the defects which can arise in the rolling, forging, or pressing of steel are described and illustrated by normal photographs and photomicrographs. A sharp distinction is drawn between defects attributable to faulty pre-treatment of the steel and those which occur during the actual deformation. A special section deals with red and hot shortness, and with methods of avoiding this source of defects. A series of photographs is included to serve as a reference by which the source of defects arising in rolling, forging, and pressing can be readily assessed.—J. P.

Alloy Steel Sheets: Stainless Steel and High-Speed Steel at Samuel Osborn and Co., Ltd. (Iron and Steel, 1950, vol. 23, Aug., pp. 339–343). An account is given of the production of alloy steel sheets by Samuel Osborn and Co., Ltd. Particular attention is given to stainless-steel sheet production, the operation sequence being listed and the plant described. Attention is drawn to an unusual four-armed rotating-jib crane which serves the annealing furnace. The production of high-speed steel sheets is also briefly described.—G. F.

Austrian Developments: Provisions for a New Semi-Continuous Strip Mill. (Iron and Steel, 1950, vol. 23, Dec., pp. 499–500). A brief account is given of a semi-continuous strip mill being installed at the Vereinigte Oesterreichische Eisen- und Stahlwerke A.G., Linz, where Austrian plate and sheet production will be concentrated. The location of the plant and the mineral resources are also briefly described.

G. F.

Present Position of Cold Strip Rolling in the United States of America. W. Harkort. (Stahl und Eisen, 1951, vol. 71, Feb. 15, pp. 170–183). The processes now employed in the U.S.A. for cold rolling, cleaning, pickling, and tinning steel are reviewed.—J. P.

Roller Guides in Modern Merchant Mill Practice. C. S. Lambert. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 79–88). The advantages of substituting rolling contact for sliding contact are briefly discussed and the applications of the principles to rolling-mill design are enumerated. Stress is laid on the advantages of roller guides wherever high torque twist, free of shearing, is required. Roller guides, it is claimed, minimize surface defects on finished materials. A number of roller guides used in merchant mills are described. Operating and design features are discussed as well as various materials and maintenance requirements.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Steam Shunting Locomotives for Steel Works. (Engineer, 1951, vol. 191, Apr. 20, p. 519). A description is given of one of three 0–6–0 saddle tank shunting locomotives built for The Steel Company of Wales, Ltd., by W. G. Bagnall, Ltd., Stafford. They will be capable of hauling seven 65-ton ladle cars up a gradient of 1 in 100 and of negotiating curves of 170 ft. radius. The locomotives have 18-in. cylinders and weigh 52 tons.—M. D. J. B.

A Billet Shear. (Engineer, 1951, vol. 191, Mar. 30, p. 426).

Billet Shears. (Iron and Steel, 1951, vol. 24, June, pp. 229–231.) This article describes the first of five 5-in. billet-shearing machines manufactured by The Head Wrightson Machine Co., Ltd., Middlesbrough. The machine will cut both cold and hot billets and will cut continuously at 17 cuts/min.

M. D. J. B.

Coil Handling. (Mechanical Handling, 1951, vol. 38, Apr., pp. 134–136). The paper describes the coil-handling equipment in use at the works of Richard Johnson and Nephew, Ltd., in particular the continuous mill and coil-handling plant which feed wire rods to the rest of the factory.—D. H.

High-Capacity Electric Overhead Travelling Crane Installed at Stafford Works of the English Electric Company, Limited. (Iron and Coal Trades Review, 1951, vol. 162, Mar. 23, pp. 691–694). Details are given of the design and construction of a new electric travelling crane at the English Electric Co., Ltd., Stafford. The crane, built by Wellman Smith Owen Engineering Corporation, Ltd., is of the double-trolley type and can handle a total load of 350 tons. It has a hoisting

speed of 5 ft./min., a cross-traversing speed of 55 ft./min., and a long-travel speed of 115–165 ft./min. The crane, with cross beam, weighs 250 tons, and is installed for handling heavy power-generating sets, particularly hydrogen-cooled alternators.—G. F.

Contribution to the Problem of Anti-Friction Bearing Life. A. Kohaut. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Apr. 1, pp. 257–261). The author points out the inadequacy of Palmgren's classical analysis of the life of anti-friction bearings. He shows, by means of frequency distribution curves, that Palmgren's results lead one to suspect a heterogenous population, and confirms that data obtained by DIN (German Engineering Standards) on two types of bearings (1309 and 6309) fit in with the sum of three log normal-frequency curves with the following statistics: 43% of the bearings have an average life 22·5% of the rated life, 48% have an average life of 95% of the rated life, and 9% an average life of 285% of the rated life. He suggests that his statistical analysis has a physical basis, *i.e.*, the three populations probably represent bearings which fail because of fatigue of inner races, outer races, and of rollers (balls) respectively. This hypothesis should be tested in future investigations which should preferably be made by determining separately the ' rolling fatigue ' of the three parts of roller or ball bearings.—J. G. W.

LUBRICANTS AND LUBRICATION

The Characteristics of Lubricating Oils. C. Carola. (Rivista di Meccanica, 1951, vol. 2, Jan. 25, pp. 5–9). [In Italian]. The author discusses the various requirements which a good lubricating oil must satisfy. The criterion of viscosity is dealt with and a number of viscosity meters are described; amongst these are the Engler and Redwood apparatus and the Saybolt, Ostwald, and Vogel-Ossag equipment.—M. D. J. B.

The Lubrication of Machines. G. Ceradelli. (Rivista di Meccanica, 1951, vol. 2, Feb. 25, pp. 11–14; Mar. 10, pp. 19–21). [In Italian]. A description is given of the general characteristics of lubricants. The phenomena of friction and the mechanics of lubrication are discussed together with the problems which must be overcome in good lubrication. The behaviour of various types of lubricant is considered and modern systems of lubrication reviewed. Gümbel's theory for the behaviour of bearing surfaces is briefly described and numerical examples are given showing the method of determining the maximum permissible load on bearings.—M. D. J. B.

Viscosity Index. C. Carola. (Rivista di Meccanica, 1950, vol. 1, Oct. 1, pp. 5–7). [In Italian]. The author shows how lubrication depends on factors such as the quality of the materials and lubricants, the surface conditions of the contact areas, and the ambient conditions. Special attention is given to a method of assessing the viscosity-temperature characteristics of oil lubricants and information is given on the viscosity index of oils.—M. D. J. B.

The Lubrication of Rough Steel Surfaces by a Series of Metallic Soaps. F. T. Barwell and A. A. Milne. (British Rheologists Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 44–48). This note describes the results of friction experiments using metallic soaps, a fatty acid, an ester, and a straight-chain hydrocarbon, all of approximately equal chain length, to lubricate rough steel surfaces. An empirical relation between friction and velocity was found for metallic soaps. The melting point of the solid lubricants is shown to be very critical, higher temperatures resulting in a sudden marked increase in friction. It is shown that the metallic soaps are the best lubricants, while the hydrocarbon was very poor.—J. A. L.

The Lubrication of Metals by Long Chain Organic Compounds. K. V. Shooter. (British Rheologists' Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 49–51). This note describes the results of an investigation of the lubrication of several metals by fatty acids. The friction results show that reaction and soap formation occur and that more than a monolayer of soap on each sliding surface is required for good lubrication.—J. A. L.

Surface Welding and the Extreme Pressure Lubricant. G. I. Finch and R. T. Spurr. (British Rheologists' Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 79–82). When two surfaces are brought into contact the surface oxide films prevent intermetallic welding. The films may be ruptured by sliding the surfaces over one another or by applying sufficient pressure to cause plastic flow at the interface. The ease with which surfaces weld on sliding depends upon their rigidity and the nature and thickness of the surface films. Extreme pressure additives react with the surface oxide to form a compound which is more fusible than the metal. If the local temperature should rise sufficiently during sliding, this compound will melt and smear over the surface, and act as a temporary lubricant.—J. A. L.

The Effect of Lubrication on Friction, Wear, and Abrasion. P. Grodzinski. (British Rheologist's Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 86–90). Experimental data are presented on the lubrication of a grinding surface. The coefficient of friction was measured by an electronic dynamometer, and between a cast-iron disc and a lubricated diamond surface. Using various oils, the friction coefficient was generally below 0·08 without diamond powder and about 0·11 with the powder.—J. A. L.

Lubricant Coatings on Wire for Bolt and Rivet Manufacture. W. E. Hill, jun. (Wire and Wire Products, 1950, vol. 25, Dec., pp. 1046, 1074–1078). A lubricating compound to coat wire for cold-heading purposes is discussed. It is claimed to produce an exceptionally good film suitable for bolt making under most adverse conditions. The only information given about the nature of the lubricant is that it is in the form of a solution.—J. G. W.

Sleeve Bearings with Simple Hydrodynamic Lubrication. (Multiple Sliding Face Bearings). W. Frössel. (Stahl und Eisen, 1951, vol. 71, Feb. 1, pp. 125–128). Although, theoretically, conditions in a cylindrical sleeve bearing should be those of hydrodynamic lubrication, in practice there results a mixture of boundary and fluid lubrication. The use of multiple sliding face bearings to achieve fluid lubrication is demonstrated and their advantages are described. They should find application in high-speed machines.—J. P.

WELDING AND FLAME-CUTTING

The Automatic Welding of Very Thick Boiler Steels with Heavy Arcs. K. V. Liubavskii and B. I. Lazarev. (Avtogennoe Delo, 1949, No. 1, pp. 7–15). [In Russian]. An account is given of an investigation of the submerged-arc welding with heavy arcs of 60–90-mm. boiler steel plates, including some containing 0·4–0·5% of molybdenum. Special attention was paid to the influence of the flux as this affects the maximum length of arc; this length is increased by easily ionized components in the flux. Oscillographs are reproduced to show the enhanced stability of arc voltage and amperage obtained by correct choice of flux. The best effects on the surface of the seam were produced by fluxes giving melts of high viscosity and solidification temperatures. The most satisfactory welds were obtained with either of two fluxes having the following respective compositions: SiO_2 46·5, 44·0%; MnO 33·0, 43·0%; Ca (total) 5·33, 4·04%; Al_2O_3 2·86, 5·09%; FeO 1·3, 1·2%; titanium trioxide 5·97, 0%; oxides of sodium and potassium 1·18, 1·18%; MgO 2·5, 0·78%. Plates 60, 70, and 90 mm. thick were used in the tests. Test pieces were cut from various positions in the welded seam for analysis, visual examination, and tensile, bend, and impact tests. For the carbon steels the tests were carried out at room temperature, but for the molybdenum steel there were additional tests at 350 and 510° C. With the comparatively small plates used (200 × 500 or × 700 mm.), no preheating was necessary to avoid cracking, but it is considered that large parts should be heated to about 200–250° C. before welding.—S. K.

The Heat-Treatment of Welded Tube Joints in High-Pressure Boilers. V. G. Dolgikh. (Avtogennoe Delo, 1949, No. 1, pp. 24–25). [In Russian]. Hardness and bending tests and examinations of microstructure were made on butt-welded specimens of chromium–manganese steel tubing, 42 mm. in dia. after the following heat-treatments: Normalizing at 900° C. with soaking for 2 or 5 min.; normalizing at 900° C. with soaking for 2 min. followed by tempering at 650° C. for 2 hr., and annealing at 900° C. and controlled cooling in the furnace. The results showed the last to be the best method.—S. K.

The Rational Sequence of Operations for Welding Boiler Drums. I. P. Trochun. (Avtogennoe Delo, 1949, No. 1, p. 27). [In Russian]. The manufacture of boiler drums is given as an example of the way in which the correct sequence of operations can reduce residual stresses in the weld seam and the deformation of the parts.—S. K.

A Graph for the Determination of the Volume of Air Being Removed from the Welding Booth. V. S. Kozachenko. (Avtogennoe Delo, 1949, No. 1, pp. 28–29). [In Russian]. Graphs are given for the performance of suction-type ventilators.—S. K.

A Contribution on the History of the Development of Russian Welding Engineering. D. I. Navrotskii. (Avtogennoe Delo, 1949, No. 1, pp. 3–5). [In Russian]. An account is given of the developments in welding methods made in Russia at the end of the 19th and the early part of the 20th centuries.—S. K.

On the Appropriation by American Firms of Russian Inventions in the Sphere of Electric Welding. D. A. Dulchevskii. (Avtogennoe Delo, 1949, No. 1, pp. 5–6). [In Russian]. It is stated that the "Unionmelt" process of submerged-arc welding was anticipated by seven years by a Russian patent granted in 1929, the diagram given in this patent being reproduced in support of this.—S. K.

Let Us Accumulate More Profits Than Planned! G. A. Nikolaev. (Avtogennoe Delo, 1949, No. 1, pp. 1–2). [In Russian]. The special advantages of welding are considered in relation to the economy of the U.S.S.R. and wider application is advocated. The development of submerged-arc welding with a 3-phase current is considered important.—S. K.

Notes on the Article by N. N. Dobrokhotov, "The Reactions of Elements and Oxides in the Welding Bath during the Welding of Metals." M. M. Timofeev. (Avtogennoe Delo, 1949, No. 1, pp. 29–30). [In Russian]. Arguments are advanced against the assumption made by Dobrokhotov in his recent article of the existence of thermodynamic equilibrium under welding conditions. His statement that the activity of free FeO in the acid slag is not affected by the replacement of MnO by lime is also challenged.—S. K.

The Second Meeting of Technologists from the Works and Institutes of the Ministry of Heavy Industry of the U.S.S.R. I. D. Brinberg. (Avtogennoe Delo, 1949, No. 1, pp. 31–32). [In Russian]. Summaries are given of papers presented at a conference held in Leningrad in October, 1948, at which the following subjects were dealt with: The introduction of high-productivity methods and organization in boiler manufacture; new equipment for submerged-arc welding; recent developments in welding methods; devices for assembling and welding of thick boiler steels; welding of pressure vessels; some new welding electrodes and the mechanization of their production; and precision flame-cutting and flame-machining. Experiences at works throughout the U.S.S.R. were compared. S. K.

The Use of Automatic Welding in the Production of Oil Storage Tanks. G. V. Raevskii. (Avtogennoe Delo, 1949, No. 1, pp. 16–21). [In Russian]. An experimental oil storage tank of 240 cu. m. capacity was constructed to test a new method intended for tanks having capacities from 100–700 cu. m. The base and wall of the tank were prefabricated, using automatic electric welding and flame-cutting. The roof is the only part welded at the site.—S. K.

On the Mechanical Testing of Welded Joints. F. I. Razdui. (Avtogennoe Delo, 1949, No. 1, pp. 21–22). [In Russian]. Some of the instructions published in the U.S.S.R. for the mechanical testing of welded joints are criticized as vague and liable to give misleading results. New instructions, based on thorough research, are advocated.—S. K.

The Use of Temperature Control in the Spot-Welding of a Carriage for the 'Metro.' P. V. Mumrikov. (Avtogennoe Delo, 1949, No. 1, pp. 22–23). [In Russian]. A description is given of the successful use in the construction of underground railway carriages of spot-welding, controlled by temperature regulation. A constantan wire passes through a hole in one of the electrodes, and is fused to the copper contact surface to form a thermocouple. A photoelectric temperature regulator switches off the current when the surface has reached the correct temperature.—S. K.

Multiple-Pass Automatic Welding of Thick Boiler Steels. K. V. Liubavskii and B. I. Lazarev. (Avtogennoe Delo, 1949, No. 2, pp. 1–7). [In Russian]. The best conditions for welding boiler steel in thicknesses of 70–90 mm., by depositing the metal in a series of passes with an automatic submerged-arc of medium strength were sought, using plates 200 × 500 or × 700 mm. of rimming low-carbon steel or silicon-killed molybdenum steel. In all cases the welding electrodes contained 0·35–0·86% of manganese. Up to 28 seams were deposited per joint at a rate of 28 m./hr. at 950–1050 amp. and 35–40 V. to give a staggered cross-sectional structure. Successful results were obtained with three fluxes, the compositions of which are given. Further experiments showed that the number of passes could be reduced by making a backing weld, either manually or automatically, and the edge preparation recommended for various cases is given. The successful results obtained are taken as further evidence for the suitability of high-manganese fluxes of low viscosity, which enable electrode wire with a manganese content normal for low-carbon steels to be used.—S. K.

The Argon-Arc Welding of Thin Sheets of Stainless Steel without a Filler Metal. A. G. Mazel. (Avtogennoe Delo, 1949, No. 2, pp. 8–13). [In Russian]. An investigation is described on the argon-arc butt-welding without filler metal of sheets 1·5 mm. thick of an alloy steel (C 0·09%, Cr 17%, Ni 9·76%, Ti 0·75%, Mn 0·56%, Si 0·54%). The strengths of current used were 42–134 amp., the speeds of welding being 9·1–32·6 m./hr. The joints were subjected to mechanical tests at temperatures up to 800° C., to corrosion tests and X-ray and metallographic investigation. Among the conclusions drawn are the following: (1) Good results are obtained using an A.C. arc with a superimposed H.F. current; (2) a D.C. arc gives poor results; (3) mechanical movement of the arc gives the best seams; (4) 0·25 mm. is the greatest gap width permissible; (5) there appears to be a linear relationship between the optimum values of current strength and welding speed; (6) at 800° C. the tensile strength of the weld is 90–97% of that of the base metal; (7) the mean impact strength of the welded specimen is 79·5% of that of the base metal; and (8) the seams are free from visible defects, but show a tendency to intercrystalline corrosion.—S. K.

Arc Voltage as a Characteristic of the Type of an Electrode. A. A. Erokhin. (Avtogennoe Delo, 1949, No. 2, pp. 13–17). [In Russian]. Based on experiments with various electrodes, the concept of rated voltage in arc welding is developed, this being the arc voltage with the length of arc normal for the particular electrode under standard conditions. The rated voltage depends both on the composition and the quantity of the electrode covering and is an important characteristic of electrodes. Under otherwise similar conditions this characteristic determines the power of the arc and the effects dependent on it.—S. K.

Welding the Dashava-Kiev Gas Pipeline. A. S. Falkevich. (Avtogennoe Delo, 1949, No. 2, pp. 18–22). [In Russian]. From experience gained in the construction of a pipeline for conveying natural gas to the Kiev region the following conclusions are drawn: Mechanized methods of welding, especially gas-pressure welding and automatic submerged-arc welding must be used as much as possible; gas pressure-welding can be successfully applied both to thin- and thick-walled tubing and is specially suitable for short lengths of tube; automatic submerged-arc methods should be used for welding tubes in sections up to 40–50 m. long; with manual arc welding, the greatest possible use should be made of centring and handling devices. The most convenient method for controlling the quality of the welds is gamma-ray testing.—S. K.

Electric Hard-Facing of Punches and a Wood-Working Tool. P. M. Sapov, N. P. Trunin, and Ya. F. Karasev. (Avtogennoe Delo, 1949, No. 2, pp. 26–28). [In Russian]. Successful hard-facing of punches with alloy steel was carried out in special graphite or copper moulds surrounding the prepared end of the tool. Covered electrodes were used, the welding current being 45–50 amp. per millimetre of the core diameter. Mechanical working of the hard-face was carried out after annealing, and the metal was then hardened.—S. K.

Welding with a Three-Phase Arc at Uralmashzavod. G. P. Mikhailov, V. V. Stepanov, and A. A. Kirillov. (Avtogennoe Delo, 1949, No. 2, pp. 22–23). [In Russian]. Some successful practical developments at a Ural factory of laboratory work on three-phase arc welding, and a machine for the automatic process under flux are briefly described. The relative productivities of three-phase automatic, three-phase manual, and normal single-phase arc welding were found to be in the ratio of approximately 23 : 12 : 1, respectively.—S. K.

A Portable Distributing Centre for Electric Welding Apparatus. A. V. Makushin. (Avtogennoe Delo, 1949, No. 2, pp. 28–30). [In Russian]. A description is given of a portable distributing centre designed for working in restricted spaces, such as are encountered in the construction of electrical power plant. It is capable of supplying simultaneously three welding transformers, and connections can also be made to enable two welding installations to be worked in parallel.—S. K.

Some Metallurgical Problems in the Automatic Submerged-Arc Welding of EYal-T Steel. K. V. Liubavskii. (Avtogennoe Delo, 1949, No. 4, pp. 1–7). [In Russian]. The thermodynamics of the reaction between metal and slag in welding in general and in the submerged-arc welding of a stainless steel in particular are considered. Special attention was paid to the intake by the seam metal of titanium and niobium in relation to the composition of the flux and electrode wire. It was found that resistance to intercrystalline corrosion was increased by contents of about 1% of niobium or 0·7% of titanium.—S. K.

Automatic Welding of Stainless Steel Type EYal-T. I. N. Gersimenko and E. M. Lapitskaya. (Avtogennoe Delo, 1949, No. 4, pp. 7–9). [In Russian]. Details are given of a special flux for the automatic submerged-arc welding of 10-mm. thick sheets of a Russian stainless steel. The flux had the following composition: Si 36·4%; total Ca 29·7%; MgO 15·5%; Al_2O_3 6·4%; and FeO 0·71%. Niobium-containing electrode wire was used (Nb 1·3% min.) as this resisted intercrystalline corrosion. The currents, voltages, and speeds of welding used were: 550–650 amp., 34–38 V. and 28–32 m./hr., respectively.—S. K.

Investigation of Single-Pass Automatic Submerged-Arc Butt-Welding of SKhL2 Steel. A. V. Obukhov and M. M. Kraichik. (Avtogennoe Delo, 1949, No. 4, pp. 9–15). [In Russian]. The steel used contained C 0·16%, Mn 0·63%, Si 0·35%, Cr 0·72%, Ni 0·47%, Cu 0·45%, Mo 0·05%, S 0·003%, and P 0·02%. Plates 10 or 14 mm. thick were butt-welded in a single pass with an automatic submerged arc, current strengths and voltages being 960–1060 amp. and 30–38 V., respectively. Specimens were subjected to bend, tensile, hardness, and impact tests, either as obtained or after low- or high-temperature tempering or normalizing. The impact tests were carried out at − 40, − 30, and − 20° C. as well as at room temperature, Izod notching being found to give the greatest sensitivity to the type of heat-treatment undergone.—S. K.

The Influence of the Electrical Characteristics of Resistance Machines on the Stability of the Welding Process. D. S. Balkovets. (Avtogennoe Delo, 1949, No. 4, pp. 15–17). [In Russian]. The stability of a repetitive process of resistance welding is considered to depend mainly on the reproducibility of the heat generated at the welding points. The factors influencing this are discussed in terms of an equation giving the heat generated in terms of the current strengths, the resistances, and the duration of the electrical impulse. The most effective way of improving the stability is said to be by increasing the impedance.—S. K.

Universal Welding Carriages Constructed by TsNIITMASh and Experience of Their Use in Industry. I. L. Brinberg. (Avtogennoe Delo, 1949, No. 4, pp. 25–30). [In Russian]. Three types of welding carriage for automatic submerged-arc welding, built in the U.S.S.R., are described. The range of main operating conditions covered by these three machines is: Current strength, 300–2000 amp.; speed of feed of electrode wire, 0·32–4·8 m./min.; speed of travel, 6–320 m./hr. All have independent methods for feeding the electrode wire, and two have continuous regulation of the speed of this process and of the speed of travel.—S. K.

The Characteristics of Useful Power and Efficiency of Resistance Welding Machines. A. Z. Blitshtein. (Avtogennoe Delo, 1949, No. 4, pp. 17–24). [In Russian]. A detailed theoretical examination is made of the influence of the electrical characteristics of resistance welding machines on the stability and efficiency of the welding process. Curves of the useful power against strength of welding current are drawn for various values of the power factor.—S. K.

Seam Welding Machine for Welding Stainless and Heat-Resisting Steels and Alloys. F. I. Kisliuk and E. M. Eskin. (Avtogennoe Delo, 1949, No. 5, pp. 27–30). [In Russian]. A description is given of a 75-kVA. machine satisfactorily used for making longitudinal and transverse seams in stainless and heat-resisting steels and alloys in thicknesses of up to 1·5 mm.—S. K.

Automatic Welding of Small Parts. Z. M. Ryzhik. (Avtogennoe Delo, 1949, No. 5, pp. 21–23). [In Russian]. An account is given of the successful use of automatic submerged-arc welding in the manufacture of flanged cylinders and lids of low-carbon steel, about 400 and 500 mm. in dia. respectively, for explosion-proof electric motors. The replacement of the manual by the automatic technique of arc welding increased productivity 500–600% and greatly improved the regularity and quality of the seams.—S. K.

An Experiment in the Production of Large-Diameter Spherical Tanks under Constructional Conditions. Iu. S. Letnikov. (Avtogennoe Delo, 1949, No. 5, p. 20). [In Russian]. An account is given of the installation, with the aid of arc welding, of a flanged spherical tank, 3 m. in external diameter, with a 14-mm. wall, inside a welded column, during the reconstruction of an oil refinery.—S. K.

Welding a Low-Alloy Steel with a High Phosphorus Content. D. M. Levykin. (Avtogennoe Delo, 1949, No. 5, pp. 18–19). [In Russian]. Experiments are described on the arc welding of steel plates (C 0·12%, Mn 0·9%, Si 0·3%, S 0·003%, P 0·15%, and Cr + Ni + Cu + Al 2·3%). Electrodes 4 or 5 mm. in dia. were used with direct currents of 160–180 and 200–220 amp., respectively. Both types of electrode gave joints with properties not inferior to those of the base metal. The microstructure of the base metal in the heated zone was found to consist of small pearlite regions, that of the seam metal being dendritic, consisting of ferrite and sorbitic pearlite.—S. K.

Flux Backings in the Automatic Welding of Containers. I. N. Gerasimenko. (Avtogennoe Delo, 1949, No. 5, pp. 16–17). [In Russian]. The use of a flux backing enables automatic submerged-arc welding to be carried out with gaps of 2–2·5 mm. Brief accounts are given of flux cushions in which the flux is compressed by the weight of the parts being welded and of those in which special devices using compressed air have to be employed. Examples are given of the use of flux backings in the submerged-arc welding of plates and of the internal and external seams of boiler plates.—S. K.

The Technology of the Automatic Submerged-Arc Welding of Very Thick 15-M Steel as Used for High-Pressure Boilers. B. I. Lazarev and I. D. Davydenko. (Avtogennoe Delo, 1949, No. 5, pp. 10–16). [In Russian]. An account is given of the welding of 0·16% carbon steel plates 70 and 90 mm. thick using multiple and single-pass automatic submerged-arc processes. For the former (with 17 runs) the current varied from 900 to 1050 amp., the voltage from 34 to 40 V., and the welding speed from 26 to 28 m./hr. For the latter the corresponding figures were 2600 amp., 43–46 V., and 6·2 m./hr. It is concluded that the methods tested are entirely satisfactory.—S. K.

Automatic Flash Butt-Welding and Some of Its Electrical Characteristics. A. M. Lushnikov. (Avtogennoe Delo, 1949, No. 5, pp. 7–9). [In Russian]. A flash butt-welding machine is described, having automatic movement of the parts to be welded and automatic regulation of the current. Unskilled operators can use these machines.—S. K.

The Characteristics of Oxy-Acetylene, Atomic Hydrogen, and Arc Welding of Sheets of YaI-T Stainless Steel. A. G. Mazel. (Avtogennoe Delo, 1949, No. 5, pp. 1–4). [In Russian]. An account is given of experiments carried out to compare the efficiency of various methods for butt-welding sheets 0·5–2·5 mm. thick of a low-carbon chromium steel. The welded specimens were subjected to tensile tests at temperatures up to 850° C., and the depths of penetration and the resistance to corrosion were determined. Arc welding was found best for butt-welding sheets thicker than 1·5 mm., atomic hydrogen being preferable for thinner sheets. Oxy-acetylene welding is recommended only for those cases in which the other processes cannot be used.—S. K.

Industrial Testing of Electrodes MEZ-04. E. P. Leonov. (Avtogennoe Delo, 1949, No. 6, p. 24). [In Russian]. Results of comparative tests on specimens welded with three different types of coated electrode are reported.—S. K.

New Seam Welding Machines. I. A. Filanovich. (Avtogennoe Delo, 1949, No. 6, pp. 22–23). [In Russian]. Descriptions are given of the construction and performance of some new machines, made in the U.S.S.R., for welding longitudinal and transverse seams.—S. K.

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Use of Automatic Welding with a Three-Phase Arc in Railway Wagon Construction. G. P. Mikhailov, E. I. Bobrov, and A. M. Solntsev. (Avtogennoe Delo, 1949, No. 6, pp. 20–21). [In Russian]. A description is given of modifications made in the construction of a welding carriage, of a type widely used in ordinary automatic submerged-arc welding, to enable it to be used with a three-phase arc. The best results were obtained with distances between the ends of the electrodes of 15–20 mm. It is suggested that to raise the welding speed to 80–100 m./hr. a special carriage and head for working with currents of 1500–1600 amp. would be required.—S. K.

Resistance to Moisture of Electrode Coatings. E. D. Lonskii. (Avtogennoe Delo, 1949, No. 6, pp. 17–20). [In Russian]. Experiments are described which were carried out to find the best conditions for storing coated welding electrodes and the influence of the moisture taken up by the coatings on their properties.—S. K.

The Automatic Flash Butt-Welding of Chromium–Molybdenum Tubes. A. S. Gelman and N. S. Kabanov. (Avtogennoe Delo, 1949, No. 6, pp. 8–16). [In Russian]. An automatic drive is described which was successfully used in the automatic flash butt-welding of tubes 32 mm. in inside dia. with a 10-mm. wall. It is claimed that the drive described can be used with any manually operated machine to deal with a wide range of work with cross-sectional areas up to 600 sq. mm.—S. K.

The Work of the Welders VNITO in 1948. G. A. Nikolaev and M. S. Nikitin. (Avtogennoe Delo, 1949, No. 6, pp. 30–31). [In Russian]. The work of technical bodies dealing with welding is reviewed. During 1948 this included, besides the solution of many practical welding problems, the development and popularization of high-productivity methods such as gas pressure welding and automatic submerged-arc welding.

S. K.

The Activities of LONITOS in 1948. N. O. Okerblom and A. S. Kogan. (Avtogennoe Delo, 1949, No. 6, pp. 31–32). [In Russian]. A general picture is given of the activities of technical welding organizations in the Leningrad region.

S. K.

The Prior Claims of Russian Science in the Field of Three-Phase Arc Welding. N. S. Siunov and G. P. Mikhailov. (Avtogennoe Delo, 1949, No. 6, pp. 4–5). [In Russian]. Russian work on the development of arc welding in general, and three-phase welding in particular is described, and it is concluded that the latter is a purely Russian invention.—S. K.

Flexible Guides for Automatic Welding Machines. A. G. Semenov. (Avtogennoe Delo, 1949, No. 8, pp. 31–32). [In Russian]. The flexible drives described are made of 'rubberized' cotton-paper belting strips 20 mm. wide and 8 mm. thick, attached to a base of the same material and thickness.

S. K.

Suspended Spot-Welding Machines Type MTPG-75. N. A. Katsnelson. (Avtogennoe Delo, 1949, No. 8, pp. 26–31). [In Russian]. Details are given of a 75-kVA. spot-welding machine for use in the manufacture of motor cars, and examples are given of welding guns which can be employed with it.—S. K.

A New Type of Rotary Transformer for Tube Welding. I. A. Filanovich. (Avtogennoe Delo, 1949, No. 8, pp. 23–25). [In Russian]. Several types of rotary transformer for electric welding tubes are described. In these instruments the electrode rings are attached to the outer casing, which also forms the secondary winding. The electrode rings are suitably grooved for the diameter of the tube being welded and are easily changed to deal with different tube diameters. The transformers have a high performance and produce secondary currents of 20,000–30,000 amp. Welding speeds of 40 m./min. have been achieved in the manufacture of tubes 8–25 mm. in dia.—S. K.

Automatic Equipment for Welding Locomotive Boilers. A. V. Shadrin. (Avtogennoe Delo, 1949, No. 8, pp. 16–20). [In Russian]. Welding machines and stands used in the automatic submerged-arc welding of Russian locomotive boilers are described.—S. K.

The Temperature of the Welding Arc. K. K. Khrenov. (Avtogennoe Delo, 1949, No. 8, pp. 14–15). [In Russian]. A theoretical discussion involving several approximations and assumptions leads to the conclusion that the temperature (° K.) of a welding arc is roughly equal to 800 times the effective ionization potential in volts of the arc gas. Temperatures calculated by this formula for an ordinary welding arc with steel electrodes are said to be of the same order of magnitude as the few experimental values available. The main approximation in the derivation of the equation is that heat lost from the arc to the surroundings takes place mainly by radiation, and it is thus not applicable to arcs burning in a rapid stream of gas.—S. K.

Multi-Layer Automatic Submerged-Arc Welding of Cylindrical Parts of Chromansil Steel. Ya. A. Zavyalov. (Avtogennoe Delo, 1949, No. 8, pp. 13–14). [In Russian]. Experiments are described on the automatic submerged-arc welding of circumferential seams on thicknesses up to 30 mm. of a pearlitic chromium–manganese–silicon steel. With ordinary methods cracks frequently appeared in the first three layers deposited, but this could be avoided by having one or two strands of wire at the base of the groove before starting welding.—S. K.

A Universal Manual Apparatus for Submerged-Arc Welding. N. E. Nosenko. (Avtogennoe Delo, 1949, No. 8, pp. 10–12). [In Russian]. In the apparatus for manual submerged-arc welding described, the welding head carries the reel of electrode wire, the motive power for the head and wire being provided by an electric motor and transmitted through a flexible drive. The speed of welding can be continuously varied from 20 to 50 m./hr., and by gear changes the ratio of this to the rate of electrode feed could be varied from 0·8 to 2·4.—S. K.

Semi-Automatic Submerged-Arc Welding with the Use of a Hose. B. E. Paton, D. A. Dudko and I. N. Rublevskii. (Avtogennoe Delo, 1949, No. 8, pp. 6–9). [In Russian]. In the method of semi-automatic submerged-arc welding described, the welding head with the flux box attached is held and moved by the welder, the electrode wire being automatically fed to the head through a special hose which also contains suitably insulated leads for the electric current.

S. K.

The Development of Electric Welding at the "Krasnoe Sormovo" A. A. Zhdanov Works. I. M. Kryakov. (Avtogennoe Delo, 1949, No. 8, pp. 1–5). [In Russian]. An account is given of the development of electric welding at a Russian works. From 1923 to 1929 progress was slow, but after the conversion to A.C. in 1929, electric welding was extensively applied to shipbuilding and the construction of locomotives, rolling stock, machinery, and pressure vessels. After 1945 submerged-arc welding has been increasingly applied.—S. K.

Formation of Pores in Welds and the Effect of Flux Composition on the Tendency to Pore Formation. I. I. Frumin, I. V. Kirdo, and V. V. Podgaetskii. (Avtogennoe Delo, 1949, No. 10, pp. 1–11). [In Russian]. An investigation into the mechanism of pore formation in welds produced by the submerged-arc process is described. To find the composition and quantity of the gas evolved with each of four different fluxes, welding was carried out inside a hermetically sealed vessel filled with argon. In other tests the gases contained in seams produced under various conditions were determined by vacuum fusion of the test pieces. Among the conclusions are: (1) The main cause of pore formation is the solution and subsequent evolution of hydrogen, and this can be minimized by introducing fluorine compounds into the flux; (2) nitrogen also stimulates pore formation in the same way; (3) slag viscosity has no appreciable effect on seam porosity; (4) small additions of silicon, aluminium, or titanium decrease pore formation; (5) the ability of fluorine to retain hydrogen in combination in the arc suggests its use to prevent cracking in open arc welding; and (6) the views of K. V. Liubavskii on the mechanism of pore formation are in many ways not in accordance with the experimentally established facts.

S. K.

The Welding of Structures at the Staro-Kramatorsk "Ordzhonikidze" Machine Works. A. P. Gavrilov. (Avtogennoe Delo, 1949, No. 10, pp. 19–24). [In Russian]. Accounts are given of the equipment and procedure used at a Russian works for welding and testing in cases where the reliability of the joints is specially important.—S. K.

Experience in the Production of High-Grade Electrodes at the Kirov Works. I. A. Zaks. (Avtogennoe Delo, 1949, No. 10, pp. 24–25). [In Russian]. An account is given of the organizational arrangements made at a Russian works for ensuring the high quality of the covered welding electrodes produced.

S. K.

The Choice of Rational Conditions for Flash Butt-Welding. K. P. Imshennik. (Avtogennoe Delo, 1949, No. 10, pp. 12–15).

[In Russian]. Determinations were made of contact resistances at various points in a flash welding machine with specimens from 2 to 20 sq. cm. in cross-section of a 0·4% carbon steel. A study was made of energy losses with a specimen 39 mm. in diameter, under various conditions, and of the characteristics of the welding transformer used. It is concluded that : (1) When preheating is adopted the welding should be carried out with intermittent flashing ; (2) sparking should be reduced to a minimum ; and (3) for correct choice of conditions, the characteristics of the transformer and the contact resistances must be known. These may be evaluated with the aid of graphs given.—S. K.

Investigation of the Power of the Flames of Welding Torches. V. D. Nechaev. (Avtogennoe Delo, 1949, No. 10, pp. 15–19). [In Russian]. Experiments made to find the power, measured as the rate of consumption of acetylene, of the flames produced by an oxy-acetylene torch with nozzles of different sizes and with various gas pressures are described. It was possible to regulate the power in the range of 25–110% of the rated power corresponding to a given nozzle, but the optimum range was considerably less than this.—S. K.

Gas Pressure-Welding of Railway Wagon Parts. T. A. Vladimirskii, K. V. Selivanov, A. K. Shvylpov, and N. V. Pashkov. (Avtogennoe Delo, 1949, No. 12, pp. 16–19). [In Russian]. It has been found advantageous in the repair of railway wagon parts to replace the forge and flash-welding processes previously used by gas pressure-welding, and examples are given of the successful use of this method.—S. K.

Machines and Torches for Gas Pressure-Welding. T. A. Vladimirskii and M. S. Nikitin. (Avtogennoe Delo, 1949, No. 12, pp. 13–16). [In Russian]. Equipment for gas pressure-welding is described which was designed with a view to simplicity of construction and maintenance, the torches being capable of working with ordinary gas systems of high or low pressure. Details are given of four machines, one with manual application of pressure and the others with pneumatic. Three types of multi-flame, water-cooled, oxy-acetylene torch for use with the machines are described, having rates of acetylene consumption of 4500, 3500, and 5000 litres/hr.—S. K.

Straight-Line Heating of Thin Sheets by Multi-Flame Torches. N. N. Rykalin and M. Kh. Shorshorov. (Avtogennoe Delo, 1949, No. 12, pp. 5–13). [In Russian]. An account is given of an investigation carried out in connection with the gas welding of tubes from thin sheets. The work involved three phases : The measurement of the heating effect of the torches, the experimental investigation of the distribution of heat in the base metal and the theoretical study of the process. Standard multi-flame torch tips were used having a rated acetylene consumption of 1500 litres/hr., and the specimens consisted of flat plates of steel 1·5 mm. thick which could be moved under the flames in the direction of the axis of the tip.—S. K.

Some Technological Problems of Gas Pressure-Welding. A. S. Falkevich. (Avtogennoe Delo, 1949, No. 12, pp. 2–5). [In Russian]. After a consideration and classification of the various methods used in gas pressure-welding, some technological aspects are examined mainly on the basis of information taken from the literature. The quality of the weld is stated to depend mainly on the degree of preparation of the surfaces, whilst temperature, pressure, and ability to diffuse, although important, are secondary factors.—S. K.

Spectroscopic Investigation of Welds. F. S. Kudelya. (Doklady Akademii Nauk U.S.S.R., 1951, vol. 76, No. 3, pp. 393–397). [In Russian]. Spectroscopic examinations of welds and hot cracks in welds were made by analysing successive layers 0·003 mm. thick.—V. G.

Measurement of Arc Energy in Welding with Coated Electrodes. H. C. van Arum. (Lastechniek, 1950, vol. 16, Aug., pp. 132–133). [In Dutch]. In welding with coated electrodes, the arc current is determined usually from the composition of the coating and the distance between the electrode and the material. In the case of an electrode with a coating composition fixed between narrow limits, the current required to maintain the arc is dependent only on the length of arc. For different arc lengths, the necessary arc properties for welding are determined from the product of arc voltage and welding current. Relationships between the type of electrode, coating thickness, and length of arc are examined.—R. S.

The Use of Basic Electrodes for Unalloyed and Low-Alloy Steels. J. van den Berg. (Lastechniek, 1950, vol. 16, July, pp. 117–122). [In Dutch]. The use of a basic electrode for an open V-weld and the advantages of basic electrodes are considered. The use of basic electrodes for St 37-41 is less common in the Netherlands than in Sweden and Switzerland. Dutch welders will probably become more rapidly accustomed to basic electrodes since the price difference between basic and thick-coated electrodes is being reduced.—R. S.

Semi-Automatic Submerged-Arc Welding. H. C. van Arum. (Lastechniek, 1950, vol. 16, July, pp. 108–112). [In Dutch]. The well-known principles and advantages of the Unionmelt and the Lincolnweld processes are stated. The semi-automatic Lincoln machine suitable for series work is described. Some data on welding times for welding with normal coated electrodes are given. Mechanical properties of submerged-arc welds are considered.—R. S.

The Welding of Pipelines and Pressure Vessels. W. H. Vosters. (Lastechniek, 1950, vol. 16, Sept., pp. 140–143 ; Oct., pp. 161–167). [In Dutch]. Works experiences in the Dutch State Mines with welded pipes and pressure vessels are discussed. Testing and inspection methods are described.

The Welding and Construction of Steel Pressure Vessels for the Oil Industries. W. P. Kerkhof. (Lastechniek, 1950, vol. 16, Apr., pp. 47–50). [In Dutch]. After discussing the qualities of steel required for pressure vessels, the forms of stress concentration are examined. Design, construction, and welding methods are considered in relation to stresses. An example is given of a vessel working at 450° C. The permissible stresses and the working stresses in the weld are calculated according to Dutch Oil Industry Standards.

Interpretive Report, Fabrication Division, Pressure Vessel Research Committee. H. C. Boardman. (Welding Journal, 1950, vol. 29, Sept., pp. 422s–432s). An interpretation is given of contemporary scientific research in the fabrication of pressure vessels by welding. It is shown that the safety of plain carbon steel vessels will depend more upon careful design, fabrication, inspection, and testing than upon improved steel quality. The report emphasizes the illusory nature of a transition temperature for a complete vessel. The Kinzel slow notch-bend test is said to be the most realistic test since it includes all the factors affecting a weld, including thickness, prestrain, and welding.—U. E.

Welding Standards in the Construction of Steam Boilers and Pressure Vessels, and the Welding of Boilers and Steam Containers. P. Bongers and L. Capel. (Instituto de la Soldadura, 1950, Publication No. 15, pp. 7–67). [In Spanish]. A study is made of the conditions to be fulfilled by the weld metal in welded boilers and pressure vessels, and of tests, standards, and safety factors. The service conditions of boilers which are not exactly circular and cases where triaxial stresses give rise to brittle fracture are considered. The second part deals with practical applications such as the welding of flanges, tubes, etc., and includes notes on the welding of stainless steels.—R. S.

Welding High-Pressure, High-Temperature Piping. H. J. Irrgang. (Welding Journal, 1950, vol. 29, Oct., pp. 876–879). Before starting fabrication on a new material a procedure is to be set up that will accomplish satisfactory results as required by the codes and specifications for bending, forming, and welding. Practical limits are given to meet these requirements.—U. E.

Previous Investigations of Weldability. A. H. Corbett. (Journal of the Institution of Engineers, Australia, 1950, vol. 22, June, pp. 119–121). The author briefly reviews two major research projects carried out at the Rensselaer Polytechnic Institute, and at Lehigh University (U.S.A.). The effects of cooling rate and type of electrode on the hardness of the heated zone were investigated. The results of rotating-beam fatigue tests on butt-welded structural and boiler quality steels, carried out by the author, are given.—P. M. C.

Implications in Relation to Australian Practice of Recent Overseas Developments in the Application of Arc Welding to the Fabrication of Steel Structures. J. E. Kindler. (Journal of the Institution of Engineers, Australia, 1950, vol. 22, June, pp. 114–119). The author reviews the published accounts of the collapse of certain Belgian and German bridges, and of the American Liberty Ship failures. The four factors affecting cold cracking, *i.e.*, hydrogen, chemical composition and structure of the parent metal, cooling rate after welding, and stresses in the heat-affected zone are discussed in some detail. Reference is made to recent British, American, and German Welding Specifications, and some criticism and

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suggested improvement of present Australian practice are offered.—P. M. C.

Built-Up Welding and the Cementation Welding Process. A. Schroeder. (Die Technik, 1950, vol. 5, Dec., pp. 587–596). The cementation welding process enables parts to be built up using straight carbon or low-alloy steels which may subsequently be hardened to Rockwell C 65. The author points to the potentialities of the process from the point of view of economy in materials. A description is given of the cementation process with illustrations of the equipment; examples of the application are given, and the article contains several tables listing filler metals with heat-treatments and typical applications.—J. G. W.

Some Aspects of Welding Metallurgy. J. Metcalfe. (Journal of the Institution of Engineers, Australia, 1950, vol. 22, June, pp. 112–114). The author shows the general effects of rate of cooling and carbon–manganese content on the weldability of steel, this being affected by the formation of martensite. '**S**' curves are shown for three steels containing 0·35% C, 0·37% Mn; 0·54% C, 0·46% Mn; and 0·50% C, 0·91% Mn. These curves indicate that the 0·91% Mn steel is the one most prone to form hard transformation products if the cooling of the weld is too rapid.—P. M. C.

Jigs and Fixtures for Inert-Gas Arc Welding. H. A. Huff, jun. and A. N. Kugler. (Welding Journal, 1950, vol. 29, Oct., pp. 893–902). The importance of designing jigs and fixtures suitable for the inert-gas welding process is demonstrated with illustrations.—U. E.

Spot Welder with Inductive Energy Storage. (Die Technik, 1950, vol. 5, Dec., p. 576). A spot welder developed some years ago in France by Sciaky is described. It is designed for welding light metals and stainless steels for which heavy currents are needed for short periods. The working principle is briefly explained. The transformer is supplied with direct current *via* a make-and-break switch. The primary circuit is broken when the magnetizing current has reached a desired value. The welding time cannot be adjusted, but the welding current may be altered to suit different materials.—J. G. W.

Spot Welder Secondary Current Measurement. I. C. McKechnie. (Welding Journal, 1950, vol. 29, Nov., pp. 962–964). A new method for measuring the accuracy of the secondary current in a spot welder for production work is described. A copper rod fitted with a fine wire thermocouple is inserted between welding electrodes. Immediately on firing the electrodes are opened and the rod allowed to hang free in still air while the rise in temperature is read on a potentiometer. The weldability constant of some materials is calculated.—U. E.

Electrode Tip Life in Spot Welding Galvanized Steel. F. W. McBee, jun. (Welding Journal, 1950, vol. 29, Oct., pp. 531s–535s). The effect of a long series of spot welds upon the electrode tip and characteristics of the weld has been investigated. It is found that the deformation of the tip is the primary cause of poor weld strength and appearance, and a hard-tip material such as chromium-copper should be used to eliminate this deformation. An increase in contact area causes a decrease in current density with a consequent decrease in weld strength. Zinc pick-up on the electrode tips in itself does not have detrimental effects.—U. E.

Effects of Reduced Atmospheric Pressure on Arc-Welding Characteristics. M. L. Begeman, B. H. Amstead, and U. I. Mashruwala. (Welding Journal, 1950, vol. 29, Sept., pp. 433s–440s). An investigation was carried out to obtain information on optimum welding conditions at low atmospheric pressures (simulating high altitudes) and to study various characteristics of the arc such as burn-off rate, penetration, crater formation, and spatter loss. Mild-steel plates were welded with a semi-automatic welding bead in an enclosed chamber at various pressures down to 5 in. Hg absolute. Both straight (E 6013) and reverse (E 6010) polarity electrodes of the same grade, but made by different manufacturers, were studied under identical conditions. At atmospheric and lower pressures the bead width and penetration increase with increases in the energy supplied to the electrode, the bead height remaining unchanged. At reduced absolute pressures crater formation is less prominent. A decrease in pressure surrounding the arc increases the burn-off rate appreciably. Spatter loss was found to be proportional to arc length and pressure.—U. E.

The Projection Welding of 0·010 and 0·020-in. Steel Sheet. E. F. Nippes, J. M. Gerken, and J. G. Maciora. (Welding Journal, 1950, vol. 29, Sept., pp. 441s–449s). The effects of projection size and shape, welding current, electrode force, electrode tip materials, and sheet surface resistance on projection weld quality were studied. An annular ring type of projection gave best resistance to cold collapse and produced welds having greater symmetry and more consistent strengths than spherical or conical projections.—U. E.

Crack Sensitivity of Aircraft Steels. A. W. Steinberger, B. J. De Simone, and J. Stoop. (Welding Journal, 1950, vol. 29, Sept., pp. 752–764). An investigation of the relative cold-crack sensitivity of several kinds of filler metal was carried out. Type 410 stainless steel was found to have the highest crack sensitivity, followed by modified S.A.E. 4330. S.A.E. 6130 had the lowest crack sensitivity. With two exceptions (Type 310 and 347 stainless filler rods) all specimens welded by the atomic hydrogen process and air-cooled developed cracks of varying magnitude. When low-hydrogen welding processes were employed, no cold cracks occurred with even the most crack-sensitive filler metals. It shows that in the absence of dissolved hydrogen or severe stress concentrations, cold cracking will not occur even under drastic quenching conditions. The presence of carbides which are slow to dissolve during the very rapid thermal cycles involved in welding will reduce the crack sensitivity without necessarily reducing the ultimate physical properties of the steel after heat-treatment.—U. E.

Effect of Low-Temperature Cooling Rate on the Ductility of Arc Welds in Mild Steel. A. E. Flanigan, S. I. Bocarsky, and G. B. McGuire. (Welding Journal, 1950, vol. 29, Sept., pp. 459s–466s). The ductility was measured by means of a 'bead-on-plate' longitudinal notched-bend test at − 100° F. and cooling rates of the welds (quenching and air-cooling) were determined by thermocouples introduced into the molten metal during welding. It was found that low ductility is produced by rapid cooling of E 6010 welds at low temperature. By tripling the width of a typical laboratory specimen, low ductility was produced even in air-cooled welds. It is suggested that some of the benefits of preheating, especially in the case of mild steel, can be attributed to the retarding of low temperature cooling.—U. E.

Variables in Cross-Wire Welding of Dissimilar Metals. I. S. Goodman. (Welding Journal, 1950, vol. 29, Oct., pp. 863–875). Most of the variables in cross-wire resistance welding nickel, iron, molybdenum, and tungsten wires to each other in various sizes, are discussed from the viewpoints of equipment supplier, equipment user, and product manufactured. Correlations are developed between these variables to help to obtain welds with the desired properties.—U. E.

Automatic Welding in Steel Mill Maintenance. W. P. Hoffman. [Welding Journal, 1950, vol. 29, Nov., pp. 989–994). Welding machines for automatic and semi-automatic submerged-arc welding are described. The advantages of using this type of welding equipment in steel-mill maintenance are discussed and illustrated.—U. E.

A Practical Method for Obtaining Consistent Resistance Welds. J. W. Kehoe. (Welding Journal, 1950, vol. 29, Oct., pp. 844–855). A plan has been developed to apply a recommended spot-welding schedule in the 30 Westinghouse production divisions using the resistance-welding process and covering over 500 machines. This is facilitated with the aid of a current meter connected to a current transformer installed in the primary side of a resistance-welding machine. This schedule can be applied to any spot-welding machine after its characteristics are determined. The key to the plan is a chart which correlates the schedule to the machine. The plan is simple and requires only a few hours to work out.—U. E.

Welding Air-Hardening Alloy Steels. W. W. Wooding. (Welding Journal, 1950, vol. 29, Nov., pp. 552s–564s). The investigation of various procedures for the shielded metal-arc welding of an air-hardening alloy steel indicated that the isothermal-transformation characteristics of the heat-affected zone considerably influenced the weldability of the material under high restraint. The restraint imposed required utilization of preheat and interpass temperatures exceeding that at which the martensite transformation begins on cooling the material from the austenitizing temperature. At such preheat and interpass temperatures it was found that satisfactory restrained welds could be obtained only by maintaining the temperature as a post-heat for a suitable length

of time. When the scarf surfaces were clad with weld metal before the deposition of the butt weld and the accompanying restraint, satisfactory welds were obtained at relatively low preheat and interpass temperatures. Above the temperature at which the martensite transformation begins, the heat-affected zone is very sensitive to thermal shock and prone to underweld cracking. Studies were made of the effect of preheat upon cooling rates of heat-affected zones. Data indicate that the initial cooling rate resulting from the quench effect of the base plate is not materially retarded by increases in preheat temperature.—U. E.

New Procedures for Studying Electrode Coverings. J. Bland and S. Goldspiel. (Welding Journal, 1950, vol. 29, Oct., pp. 522s–529s). A new procedure for following the variations in moisture contents with time is described. An X-ray spectrometer 'fingerprint' method for the rapid classification of electrode coverings has been developed. An X-ray spectrometer is used for determining the crystal forms and amounts of titania and silica introduced into electrode coverings.—U. E.

Rehabilitation of Ore Cars. J. F. Likarish. (Welding Journal, 1950, vol. 29, Oct., pp. 837–843). The rebuilding of 400 old ore cars by welded construction is described.—U. E.

The Development of Welding and Some Applications in Railway Construction and Repairs. R. Verzillo. (Instituto de la Soldadura, 1951, Publication No. 16, pp. 5–33). [In Spanish]. The author outlines the various methods of welding and the special processes associated with welding, such as flame-cutting and hardening. The advantages of various forms of control are stated. A complete collection of drawings and photographs serves to illustrate the applications of welding to constructional and repair problems relating to steam locomotives and tenders.—R. S.

Electric Arc Welding (Contact Welding) and the Influence of Hydrogen on the Porosity and Hot Cracking of Welds, According to the Electrode Used. P. C. van der Willigen. (Instituto de la Soldadura, 1950, Publication No. 14, pp. 5–27). [In Spanish]. A review of the different types of electrode shows that there exists a great difference in the gas content and the mechanical properties of the weld. Recent progress shows that all types of electrode can be adapted for contact welding by the use of iron-powder coatings. This iron coating confers semi-conducting properties which facilitate ignition of the electric arc. The properties and advantages of the arc are examined. Some special applications of contact electrodes are given. The different behaviour of various types of coating as regards cracking and porosity in the weld metal is related to the action of hydrogen in the weld.—R. S.

Electric Resistance Welding. M. de Villota y Muniesa. (Instituto de la Soldadura, 1951, Publication No. 13, p. 36). [In Spanish]. General processes of resistance welding and definitions are discussed. The electric theory of welding is examined. Resistance welding is here classified according to the type of weld made, the mechanism used, and the methods of heating. The thermoelectric cycle, the metallurgical process, and the mechanism of seam welding are discussed. Spot welding is considered under the headings: Secondary intensity; methods of intensity regulation; causes of varying intensity and various methods of applying the current in welding.—R. S.

Welding Hygiene. A. Louviaux. (Pact, 1950, vol. 4, Dec., pp. 440–444; 1951, vol. 5, Feb., pp. 18–21). A review is made of industrial hazards arising from flame and electric arc welding, and the methods of avoiding or curing these.

J. J.

Basic Coating of Special Purpose Electrodes. I. Fiorini. (Metallurgia Italiana, 1951, vol. 43, Feb., pp. 65–71). A review is given of the developments of the different types (especially basic) of coatings on welding electrodes. The basic coating is especially advantageous for stainless steels. Details are given of tests carried out with high yield point weld metals and also with weld metals capable of withstanding wear and test.—M. D. J. B.

The Scientific and Technological Development of Welding Processes—Problems and Tasks. F. Rapatz. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 230–234). A brief survey is given of the development of electric arc welding processes.—U. E.

Welding Electrodes and the Metallurgical Behaviour of Weld Metal. P. C. van der Willigen. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 234–240). The influence of the presence of hydrogen on the quality of the weld and base metal is discussed. A summary of data on this in recent literature is given.—U. E.

The Weldability of High Tensile Steels and Theory of Crack Formation. H. F. Tremlett. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 241–251). A number of low- and high-alloy, high-tensile steels and three types of creep-resisting steel were investigated using the Reeve fillet weld test. It is shown that the weldability is a function of several variables among which is the type of electrode used. Consideration of the variables together with other evidence enables a picture to be drawn of the probable metallurgical processes which are involved when arc welding alloy steels. Desirable limits as regards composition or control of welding conditions for good weldability are suggested.—U. E.

Influence of Welding Flame on the Metallurgy of Welding Phenomena. V. Trunschitz. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 259–263). The influence of C_2H_2–O_2 content and pressure of the flame on the quality of the weld is discussed. Reference is made to work carried out by Mues in 1930.—U. E.

What Happens in Welding Arc from Covered Electrodes. W. Hummitzsch. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 262–267). Oscillographs are given showing the effect of current density and amperage of alternating and direct current on the efficiency of the metal transfer. Previous work is critically reviewed.—U. E.

Effect of Electrode Coating on the Voltage of the Welding Arc. C. Tschappat. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 267–271). This is a theoretical discussion of the different potentials involved in electric arc welding and the effect of the coating on the efficiency of the electric arc.—U. E.

Attempt at Explaining Scientifically the Behaviour of Steel. W. Soete. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 271–276). A mathematical treatment is given to obtain a relationship between the stress and deformation.—U. E.

The Behaviour of Welds under Static and Dynamic Loading. H. Melhardt. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 277–282). The Austrian Standard welding bend and tensile tests M.3052, M.3050, and B.4300/3 are described, and graphs are given showing the stress distribution in butt and fillet welds.—U. E.

New Developments in Non-Destructive Testing. F. Förster. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 284–291). A magnetic crack detecting test is described which combines the eddy-current crack detector test and the magnetic powder detector test. A feeler pin is guided along the magnetized specimen through which an alternating current is flowing. A voltage is produced when the pin moves over a crack and is recorded on a screen. A magnetic sorting bridge is also described.—U. E.

Welding Progress over the Last Ten Years in the United States. A. B. Kinzel, D. Swan, and H. Biers. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 291–295). This is a review of different automatic welding processes which have found widespread application in the U.S.A.—U. E.

Weldability of Converter Steel. H. Buchholtz. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 296–303). A number of Bessemer steel specimens were subjected to impact and bend tests. Steel of 60 kg./sq. mm. tensile strength possessed good weldability conforming with German Standard (DIN) No. 4100, but care should be taken when welding thicknesses greater than 15 mm.—U. E.

New Aspects Regarding the Fusion Welding of Structural Steels Produced in Large Tonnages. A. Legat. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 303–307). This is a review of data giving physical properties of welds.—U. E.

Flash Welding of Chromium-Steel Tubes. W. Denker. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 308–314). Flash welding was carried out on a number of chromium-steel tubes, and physical properties are tabulated.—U. E.

Problems in the Welding of High-Pressure Pipelines. H. Hauttmann. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 314–317). Weld bend tests carried

out on Aldur steel gave valuable information on the properties of welded pressure vessels, and it was shown that a steel of 58–68 kg./sq. mm. tensile strength could be welded successfully.—U. E.

Welding of Fatigue Cracks in Main Drive Shaft of a Reversing Rolling Mill. A. Scortecci. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 326–327). The repair by welding of a deep fatigue crack in the main shaft of a reversing rail mill is described. Details of the special precautions to prevent distortion are given.—U. E.

Welding of Cast Iron. V. Walter. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 327–330). The repair of cast iron by welding and brazing is discussed and measures are given to eliminate or reduce stresses.—U. E.

The Application of the "Ellira" Welding Process to Boilers and Vessels. M. Komers. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 330–335). A number of welds of different shapes were carried out and their physical properties investigated. The advantages of applying the Ellira process to the welding of boilers and vessels are pointed out.—U. E.

Metallurgy and Application of Hard-Facing. A. Schmidt. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 342–348). The process of hard-facing and its application is described. Details are given of weld deposits and their metallurgical properties.—U. E.

Argon Arc Welding. M. Brillié. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 348–352). [In French]. The argon arc welding process is described and details are given of purity of the argon gas, the tungsten electrode, and stability of the arc.—U. E.

Gas Pressure Welding. L. Wolff and O. Renner. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 356–361). The pressure welding process as developed originally by Renner is described. The relationship of welding time, temperature, and pressure was investigated and metallurgical properties are tabulated. The process is applied successfully to the welding of rails.—U. E.

Experiences Gained in the Welding of Rails. R. Walzel and H. von Laizner. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 361–367). This is a comprehensive review of the literature.—U. E.

Weldability of Stainless Chromium–Nickel Steel. F. Rapatz. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 368–370). The welding of stainless chromium–nickel steel is discussed and methods are suggested for preventing hot-shortness.—U. E.

Submerged Electric Arc Welding. L. R. D. Gargano. (Tecnica e Industria, 1951, vol. 29, Apr., pp. 279–283). [In Spanish]. The main characteristics of submerged-arc welding and the equipment are described. Two important applications in Argentina are hard facing and building up worn material (*e.g.*, rolls).—R. S.

Automatic or Manual Welding? H. Stern. (Schweisstechnik, 1951, vol. 5, Mar., pp. 25–30). A survey is given of the development and practical application of current automatic welding processes. These are compared with manual electric welding methods. The quality and physical properties are briefly discussed.—U. E.

Technique of Thermit Welding with Special Reference to the Repair of a Broken Work Roll. W. A. Baines. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 23, pp. 439–442). After a brief description of the technique of thermit welding, a detailed examination is presented of the various equipment and processes involved, including the lining and charging of the crucible, the preparation of the parts to be welded, and setting up the mould boxes. The repair of the driving end of a work roll is given as an example of thermit welding.

The Welding of Large Sections using the Thermit Process. W. Ahlert. (Schweissen und Schneiden, 1951, vol. 3, Feb., pp. 40–52). The thermit welding process for large steel sections is described. Thermochemical data are given for the chemical reactions occurring in this process. Possibilities of application are discussed and illustrated.—U. E.

Physical Properties of Welds made by the Ellira Process. E. Uhlir. (Schweisstechnik, 1951, vol. 5, Feb., pp. 16–21). The Ellira process corresponds to the Union-Melt welding process developed in America. A number of welds were carried out on a steel (Mn 0·9%, Si 0·32%, Al 0·085%). Tensile, bend, and impact tests gave good results, but the welds were subject to ageing.—U. E.

The Gas Welding of Rails. J. Kunz and W. Raabe. (Schweissen und Schneiden, 1951, vol. 3, Mar., pp. 73–83). The correct and incorrect gas welding of rails is described. Twenty different types of rails were investigated and their physical properties and weldability determined. A brief survey is given of the pressure-welding method.—U. E.

Making Disc Milling Cutters by Hard-Facing with an Electric Arc. Z. M. Ryzhik. (Stanki i Instrument, 1948, No. 2, pp. 22–23). [In Russian]. The details are given of a method for hard-facing disc-shaped mild-steel milling cutter bodies with high-speed steel, using electrodes with a coating of the following composition: Cr 18%, Mo 10·8%, V 12·1%, W 17·0%, C 3·3%, ferrotitanium 3·6%, chalk 9·0%, marble 18·0%, quartz 2·7%, fluorspar 4·5%, and bentonite 1·0%. The operation was carried out in a special copper device, the disc then being cooled under sand, annealed at 940–1100° C. and forged to approximately the required dimensions. After further annealing followed by mechanical working the disc was hardened and tempered, and the cutting teeth were ground.—S. K.

Cutting Tools Hard Faced with High-Speed Steel. W. Czyrski. (Hutnik, 1951, vol. 18, Apr., pp. 144–151). [In Polish]. Experimental production of tools with cutting edge hard-faced with high-speed steel, electrodes used in the process, and the influence of welding conditions and heat-treatment on the structure and properties of the deposited metal are described. V. G.

Angle Fillet Welding in the Vertical Position. M. Mouton. (Revue de la Soudure, 1951, vol. 7, No. 1, pp. 25–34). The author stresses economic advantages obtained with deep penetration electrodes. The process is dangerous if practised by inexperienced welders. Deep penetration is especially useful for vertical fillet-welding and is therefore useful in ship construction. An analysis is made of the various types of weld, manner of welding, characteristics of joints, and ease of welding when using different electrodes.—M. D. J. B.

Welded and Brazed Brake Bands Use 60% Less Steel. W. H. Haviland and S. M. Spice. (Iron Age, 1951, vol. 167, Jan. 11, pp. 68–70). The Buick division of General Motors is producing brake bands by projection welding and then brazing lugs on to strip instead of machining from rings; this reduces the amount of steel required per band from 5½ to 2 lb. Brazing is carried out in a reducing atmosphere (H_2 40%, CO 20%, N_2 40%) to prevent scaling and minimize carburization.—A. M. F.

The Silver Brazed Pipe Line. J. B. Ross. (Canadian Metals, 1951, vol. 14, Feb., pp. 41, 43). Silver alloy brazing is described as an efficient method of joining ferrous and non-ferrous tubes and pipes. Joints are corrosion-resistant, vibration proof, and leak-tight, and have a good exterior and interior finish. Dissimilar metals may be joined by this method.—E. C.

Manufacture of Electric Fusion Welded Pipe. J. H. Middleton. (Iron and Steel Engineer, 1951, vol. 28, pp. 66–69). This article describes a mill recently completed for the Republic Steel Corp. to manufacture expanded steel line pipe by the electric fusion submerged-arc weld process. General details are given of the mill which is designed to manufacture pipe 20–30 in. outside dia. in lengths from 27 to 31 ft. 6 in. Details are also given of ancillary equipment, plate preparation, mechanical handling, the submerged-arc welding process, electric current requirements, and the specifications for the finished pipe.—M. D. J. B.

Mass Production of 2½ Miles of Pipe Daily. D. A. Evans. (Iron Age, 1950, vol. 166, Dec. 28, pp. 68–73). This article gives a description of two mills of the U.S. Steel Corporation which produce 26-in. to 36-in. electrically welded pipe. The plates are carefully squared, formed into a **U** and then an **O** before being welded externally and internally by the submerged-arc process. The finished diameter is imparted by hydraulic expansion.—A. M. F.

Welding of Turbine Parts by Means of Electrodes Having a High Fusion Coefficient. G. Doneux. (Ossature Métallique, 1951, vol. 16, May, pp. 222–224). Arc welding by means of electrodes having a coefficient of fusion of 0·19–0·22 g./amp./min. (as compared with the standard electrodes having a coefficient of 0·13 g./amp./min.) as employed in the construction of Kaplan-type turbines for the Electricity Company of Liège is described. Rationalization of the work, avoidance of costly repairs, and a good quality of welds are claimed. P. F.

Integrated Processing Boosts Conduit Output. D. Reebel. (Steel, 1950, vol. 127, Dec. 11, pp. 94–98). A new plant of the Mahoning Valley Steel Co. produces electric welded conduit in sizes from 0·5 to 2 in. in outside dia. The operations of slitting, seam-welding, forming, induction butt-welding, cooling, sizing, shearing, straightening, chamfering and facing, electro-galvanizing, painting, and drying are completely integrated and carried out automatically. The speed of operation is up to 200 ft./min. for the 0·5-in. material.
A. M. F.

Electronic Control of Welding Equipment. C. E. Wright. (Welding Engineering Symposium: Australasian Engineer, 1951, Feb. 7, pp. 50–56). The author describes the principal electronic control systems which are in regular commercial use with resistance welding equipment.—P. M. C.

Resistance Welding Controls—Why so Many? W. E. Large. (Iron Age, 1950, vol. 166, Nov. 23, pp. 64–67). The wide range of controls that exist for resistance welding equipment is presented in chart form under the categories of current switching, firing and current control, sequencing, weld treatment, and demand reduction systems.—A. M. F.

Great Increase in Spot-Welding Speeds Made Possible by the Use of New Equipment. (Sheet Metal Industries, 1951, vol. 28, Feb., pp. 179–182). Multi-point spot welding machines for the production of such items as motor-car bodies and doors are being developed in this country by Philips Electrical, Ltd. Several typical machines, which may contain up to 200 welding heads and consume up to 250 kVA., are described and illustrated.—P. M. C.

Inspection of Butt Welded Pipe Joints. (Welding and Metal Fabrication, 1951, vol. 19, Feb., pp. 65–67). A new method of examining butt welded pipe joints as developed by E. P. S. Gardner is discussed. First, a plug about 1 in. in dia., trepanned from the joint, is polished and etched across the weld sections it contains to disclose any non-metallic inclusions or porosity. The second part of the procedure, in the case of (hidden) joints otherwise inaccessible for bore examination, is the examination of the root penetration at the back of the weld in the bore of the pipe through the hole formed by trepanning; for this purpose an 'introscope' is used.—U. E.

Results of Recent Tests on Resistance to Weld Decay of Low-Carbon Stainless Steels. G. R. Bolsover. (Sheet Metal Industries, 1951, vol. 28, Jan., pp. 73–76). Weld decay tests have been carried out on a number of 'Silver Fox' grades of 18/8 stainless steel, to show the effect of reduction in carbon content to 0·03%, and also to compare this low-carbon material with steel of somewhat higher carbon content treated with titanium. The main conclusion is that the 0·03% C steel behaves as well as the 0·06% C plus titanium steel, under standard test conditions. Accentuated tests, however, show that the latter type (with a Ti/C ratio $> 8:1$) resists weld decay better than the straight 0·03% C type.—P. M. C.

Welded Narrow Steel Sheets Used for Wide Stampings. K. Rose. (Materials and Methods, 1951, vol. 33, Jan., pp. 83, 84). Wide sheet steel (62–72 in.) is more expensive per pound than narrower sheet (36–48 in.), and the sources of supply of the former are far fewer. For these reasons, the automotive industry (in the U.S.A.) has developed seam, multiple spot, butt, and other welding techniques, by which two or more narrow sheets are welded together before pressing operations.—P. M. C.

Principles of Welding with Preheating Applied to Cast Iron. H. Turcke. (Die Technik, 1951, vol. 6, Mar., pp. 138–142). Details are given of the methods employed in welding, the behaviour of cast iron at elevated temperatures, the design of boxes and furnaces for preheating of the parts, stress-relieving treatment, welding electrodes, and auxiliary welding apparatus employed in welding.—J. G. W.

The Influence of Atmospheres and Heat-Treatment on Electric Welding. H. G. Geerlings. (Revue de la Soudure, 1951, vol. 7, No. 1, pp. 16–24). This paper is confined to the welding behaviour of plain low-carbon steels. An indication of the nitrogen and oxygen absorption in weld metals is given. The results of gas absorption on the qualities of welds produced, the heat-treatment of welds, actual welding technique, and the determination of resistance to intercrystalline corrosion are considered. Results of bending and tension tests are given. The tendency to ageing is dealt with. Finally, a comparison is made of gas contents and mechanical properties of welds obtained with continuous and alternating current welding.—M. D. J. B.

Welding Platforms. K. A. Ringdahl. (Jernindustri, 1951, vol. 32, Jan., pp. 7–15). [In Swedish]. Welding platforms serve to hold parts to be welded in the correct position, to give a 'reference plane' and to counteract shrinkage forces during the construction. Cast-iron platforms also act as absorbers for excessive heat, especially when welding sheet material. Jigs and clamps, including compressed air 'stamps' used in ship-building, are briefly described.—B. S. E.

Welding of Heat-Resisting Steels. N. Lundgren. (Teknisk Tidskrift, 1949, vol. 79, Dec. 31, pp. 1015–1019). [In Swedish]. The Jominy test has been applied to judge the weldability of various types of heat-resisting steel.—B. S. E.

An Attachment for Semi-Automatic Flame-Cutting Machines to Facilitate the Start of Cutting. P. V. Tonina. (Avtogennoe Delo, 1949, No. 6, p. 27). [In Russian]. A simple device is described for holding portable semi-automatic flame-cutting machines in the initial stages of the cutting process.—S. K.

Semi-Automatic Machine PS-2 for the Flame-Cutting of Steel. A. K. Krzhechkovskii. (Avtogennoe Delo, 1949, No. 6, pp. 25–26). [In Russian]. A description is given of one of the first semi-automatic flame-cutting machines of Russian construction. The machine weighs 65 kg. and can carry three torches. The consumptions of oxygen and acetylene, and cutting speeds are tabulated.—S. K.

The Flame-Cutting of the Ends of Z-Section Beams. S. V. Begun. (Avtogennoe Delo, 1949, No. 8, p. 32). [In Russian]. A sketch and a very brief description are given of a semi-automatic oxygen flame-cutting appliance.—S. K.

Stack Cutting with Low-Pressure Oxygen. S. V. Begun. (Avtogennoe Delo, 1949, No. 12, pp. 28–30). [In Russian]. The characteristics of flame-cutting stacks of steel sheets are outlined, and experiments are described which showed that this operation could be carried out even with appreciably thick gaps between the sheets forming the stack. The oxygen pressures used varied from 2·5 to 3·5 atm. Recommendations are made for dealing with various stack-cutting problems, and illustrations are given of typical results obtained.—S. K.

The Heating of Thin Sheets of Structural Steels in Cutting. G. B. Evseev and T. A. Degtyar. (Avtogennoe Delo, 1949, No. 12, pp. 24–27). [In Russian]. With a view to decreasing the undesirable hardening of the edges of structural sheets liable to occur in flame cutting through too rapid cooling, experiments were made with preheating of the oxygen and with additional heating of the material by means of special torches during the cutting process. The main conclusions are: (1) Preheating of oxygen to 380° C. produces no effect on the rate of cooling of the edges; and (2) for sheets 5 mm. thick this rate can be considerably reduced by means of special torches, but this may not be sufficient for certain types of steel.—S. K.

Material and Heat Balance in the Oxy-Acetylene Cutting of Low-Carbon Steel. G. L. Petrov. (Avtogennoe Delo, 1949, No. 12, pp. 20–24). [In Russian]. On the basis of experiments in which temperature distribution and material consumption were determined during the flame-cutting, with cutting speeds of 200, 240, and 300 mm./min., of low-carbon steel plates 750 × 400 × 26 mm., material and heat balances are drawn up.—S. K.

Fully Automatic, Photo-Electrically Controlled, Oxy-Acetylene Cutting Machine. H. Kunz. (Schweissen und Schneiden, 1951, vol. 3, Mar., pp. 89–91). An 'electric eye' tracing cutting machine developed in the U.S.A. is described. The electronic eye tracer head is attached to one end of the pantagraph bar and the torches to the other. The operation of the steering motor is controlled by light emitted from the base of the tracing bead which is reflected from the drawing or silhouette and picked up by phototubes. This light, which follows the outline of the drawing, is projected in the form of a spot from an electric lamp through an optical unit. Intricate shapes or contours impossible to cut with other types of tracing device, may be accurately cut with this fully automatic equipment. Low cost and ease of drawing or silhouette preparation make possible complex design reproductions while reducing operator fatigue.—U. E.

Flame-Cutting with Propane. H. Schulz. (Schweissen und Schneiden, 1951, vol. 3, Jan., pp. 2–11). Propane and acetylene gas for cutting plates 10 to 300 mm. thick were compared. Acetylene is definitely superior to propane as regards cutting time and gas consumption.—U. E.

XUM

Cutting Cast Iron. R. L. Vining. (Welding Journal, 1950. vol. 29, Sept., pp. 765–766). The technique used for cutting cast iron with a standard oxy-acetylene blowpipe is described. Illustrations are given of the different cutting nozzle angles and movement of the blowpipe during the operation.—U. E.

Electric-Arc Oxygen Cutting. H. Schmidt-Bach. (Neue Giesserei, 1951, vol. 37, June 1, pp. 210–211). The technique is described and deemed of great potential use in the foundry, The author claims it will result in real savings.—J. G. W.

Increase of Hardness at Flame-Cut Edges and Its Elimination. G. Kritzler and H. Thier. (Stahl und Eisen, 1951, vol. 71, Feb. 1, pp. 119–124). Flame-cutting tests have been carried out on carbon and low-alloy steels with simultaneous or subsequent annealing of the cut edge with annealing burners. Spectrographic and chemical analysis of the thin outer zone showed that chromium, manganese, and silicon were burned out, but that carbon and molybdenum were enriched. Preheating of the steel was advantageous in eliminating hardening, but it increased the extent of the heat-affected zone. Since usual normalizing of flame-cut components is not always possible, tests were carried out with an annealing torch travelling with the cutting torch, without success. Satisfactory results were achieved when the edges were annealed after the cutting. Suitable flame sizes and speeds for various thicknesses and steel compositions are given.—J. P.

MACHINING AND MACHINABILITY

Machinability Research. (Machinist, 1950, vol. 94, Dec. 30, pp. 1869–1873). The primary purpose of the machinability research laboratory which the B.S.A. Group has established is development work designed to lead to new tools, improved materials, and new methods of immediate value to their own companies and industry generally. The article includes sections on the method of approach, small tool design, and ceramic cutting material.—E. C. S.

Machinability and Metal Cutting. F. W. Boulger. (Canadian Metals, 1950, vol. 13, Dec., pp. 6–9, 46, 51). Machinability of metals is defined and discussed, and various methods of assessing machinability are considered. Machining properties of copper, magnesium, aluminium, and their alloys, and of stainless steels are dealt with.—E. C.

Hot Machining of Tough Alloys. H. Janes. (Machinery, 1950, vol. 77, July 20, pp. 75–78). A newly developed technique in metal cutting involves heating the work to reduce the power required for machining. This technique is particularly applicable to the cutting of stainless steels, high-temperature alloys, and other materials difficult to machine by conventional methods. After further research it should prove of value in machining tough alloys used for jet engines and gas turbines. The results of investigations of the factors involved in turning heated metal carried out for the U.S. Navy are reported.—E. C. S.

Manipulation of Corrosion- and Heat-Resisting Steels. J. A. McWilliam. (Welding and Metal Fabrication, 1951, vol. 19, Jan., pp. 19–24). Techniques are described for machining, drilling, shearing, and pressing of a few martensitic and austenitic corrosion-resistant steels before fabricating assemblies by welding.—U. E.

High-Quality Surface Finishes of Metals. M. Nogaro. (Rivista di Meccanica, 1950, vol. 1, Nov. 15, pp. 13–17). [In Italian]. The author describes the processes of obtaining high-quality surfaces on metals, and gives a number of examples where this type of finish is essential in improving resistance to wear and fatigue.—M. D. J. B.

Surface Finishes in Modern Engineering. M. Stella. (Rivista di Meccanica, 1950, vol. 1, Oct. 1, pp. 17–22; Oct. 15, pp. 15–21). [In Italian]. Information is given on the various types of surface finish in current use in ordinary and high-precision engineering. The types of surface defect are classified by size, periodicity in their occurrence, and their orientation. These irregularities and their behaviour to lubrication are examined. A standard method of specifying tolerances and requirements is given.—M. D. J. B.

Metal Cutting : Art to Science. H. Ernst. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 1–4). This preface indicates the new emphasis on fundamental principles, and the progress in production, quality, and increased tool life.—E. T. L.

Metal Cutting Research—Theory and Application. M. E. Merchant. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 5–44). This paper deals with research into the nature of the cutting process, including the force systems in making each of three kinds of chip, and the relevance of various physical characteristics. Test methods, microstructure, cutting-tool materials and shape, and cutting fluids are considered. There are 14 references. E. T. L.

Cutting Fluid Theory. M. C. Shaw. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 45–68). A cutting fluid is a lubricant and coolant. After a brief consideration of the process of cutting a metal, its action is outlined. The high pressure at the tool tip enables certain chemical reactions to proceed ; these, and also the temperature of the chip-tool interface, and practical consequences of cutting-fluid theory are dealt with.—E. T. L.

Materials and Machinability. F. W. Boulger. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 69–109). The measurement of machinability is considered, with reference to copper content, hardness, and friction coefficients. The measurement of surface finish is then examined, and materials commonly machined are compared. A final section deals with super-high-speed cutting. There are 33 references.—E. T. L.

Development of the Macrostructure of Metals by Machining. L. M. Clarebrough and G. J. Ogilvie. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 110–122). Photographs of the alterations of grain structure of lead on machining, show that they are caused by transverse irregularities due to the variation of crystal orientation. E. T. L.

Metallurgy and Machinability of Steels. J. D. Armour. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 123–168). Tests have been carried out on the maintenance of good finish, tool life, speeds and uniformity, and the results, giving recommended procedure, are set out in a series of tables. The effects of metallurgical structure, hardness, inclusions, cold work, and tool life are dealt with.—E. T. L.

Tool Steels. G. A. Roberts. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 169–198). This review considers hot hardness, toughness, and wear resistance. Carbon, medium alloy, and high-speed steels are examined, with particular reference to mechanical properties and alloy content.—E. T. L.

Cemented Carbide Tool Materials. J. C. Redmond. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 199–217). Composition, mechanical properties, commercial quality, design, and the use of carbide tools are discussed ; there is also a note on recent developments. E. T. L.

Heat in Metal Cutting. A. O. Schmidt. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 218–340). Calorimetric determinations of the heat dissipated in drilling and in milling are described, having regard to the effect of cutting fluids, rake, and the resulting surface. Cold work of the surface was studied with X-rays, and attention was paid to tool life, chromium plating, steel hardness, the advantages of positive rake angles, commercial use of carbide milling cutters, and the difficulties of milling high-strength alloys. There are 26 references.—E. T. L.

Evaluation of Machinability of Rolled Steels, Forgings, and Cast Irons. M. Field and N. Zlatin. (American Society for Metals : "Machinability—Theory and Practice," 1950, pp. 341–376). This paper deals with the determination of the machining characteristics of metals, and the application to industrial processes. Results show that coarse pearlite-graphite gives longer tool life than fine, and that ferrite is even better. Tool life depends mainly on matrix structure, and is appreciably lessened by the presence of free carbide. E. T. L.

Tool Life Testing. O. W. Boston. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 377–408). Types of tool failure and methods of evaluation of tool life are considered. It is concluded that tool life is best determined by observing tool wear directly and that a flank wear of 0·03 in. is permissible.—E. T. L.

Some Metallurgical Aspects of Grinding. L. P. Tarasov. (American Society for Metals : "Machining—Theory and Practice," 1950, pp. 409–464). Grindability is defined and considered, also grinding sensitivity of various steel phases, grinding burn, surface hardening, and injury. The correction of grinding faults is dealt with. There are 22 references.

Economics of Machining. W. W. Gilbert. (American Society for Metals: "Machining—Theory and Practice," 1950, pp. 465–485). Methods are shown for lessening cutting costs by increasing the rate of metal removal. Nomograms give the tool life and cutting speed for minimum cost.—E. T. L.

Flexible Guides for Semi-Automatic Flame-Cutting Machines. A. G. Semenov. (Avtogennoe Delo, 1949, No. 1, pp. 27–28). [In Russian]. An account is given of a type of guide for semi-automatic flame-cutting machines which is sufficiently flexible to ensure a constant distance from the tip of the torch to the sheet being cut.—S. K.

Making Special Nozzles for Cutting Torches. R. V. Vroblevskii. (Avtogennoe Delo, 1949, No. 4, p. 30). [In Russian]. A brief description is given of a two-stage method of constructing nozzles for flame-cutting torches, which facilitates the provision of the channels for the preheating flame.—S. K.

A New Powerful Cutting Torch for Surface Cutting. S. G. Guzov. (Avtogennoe Delo, 1949, No. 5, pp. 25–27). [In Russian]. A description is given of a cutting torch, type RVP-49, having provision for automatically introducing a metal rod into the preheating flame, which facilitates the start of cutting by depositing a drop of metal on the surface. Three tip sizes give ranges of oxygen and acetylene consumption of 100–700 and 2–30 litres/kg. of metal removed, respectively, the greatest rate of cutting being 10 kg./min. with a single pass.—S. K.

Removing Defects in Weld Seams with a Torch for Surface Flame-Cutting. V. A. Toropov. (Avtogennoe Delo, 1949, No. 5, pp. 23–25). [In Russian]. The flame-gouging torch has been used to remove defects in manually arc-welded gasholders.—S. K.

The Oxygen Cutting of a Metal without Continuous Preheating. I. S. Dmitriev and N. M. Madatov. (Avtogennoe Delo, 1949, No. 5, pp. 4–7). [In Russian]. The method for the oxygen cutting of steels described is based on the preheating of the oxygen by reaction with a carbon tube through which it is passed. An arc is struck between the tube and the metal, which heats the metal and the tip of the tube. When the metal reaches the ignition temperature, the current is switched off and oxygen is admitted; this maintains the temperature of the tube. The consumptions of oxygen, carbon, and electricity are given.—S. K.

A Study of Heat Developed in Cylindrical Grinding. R. E. McKee, R. S. Moore, and O. W. Boston. (Transactions of the American Society of Mechanical Engineers, 1951, vol. 73, Jan., pp. 21–34). The authors present results of an investigation of the grinding process with particular reference to the influence of the grain size of a grinding wheel and type of grinding compound used on certain criteria, *e.g.*, volume of metal removed per unit of wheel wear, unit net horsepower, surface finish, grinding rating, temperature increase in the workpiece surface, temperature increase in the grinding compound, and possible injury to the structure of the metal. D. H.

Machining of Heated Metals. E. T. Armstrong, A. S. Cosler, jun., and E. F. Katz. (Transactions of the American Society of Mechanical Engineers, 1951, vol. 73, Jan., pp. 35–43). Studies are reported of the machinability of several materials at elevated temperatures. It was found that tool life, cutting austenitic stainless steels, was increased tenfold by heating to 400° F. High-temperature alloys including vitallium machined freely at temperatures from 700° F. to 2000° F. Long curling chips and a smooth, cleanly cut surface were produced in hot-machining. The same materials cut at room temperature developed a glazed uneven surface and the chips were powdery. Austenitic manganese steel machined easily at 1200° F., as did fully hardened high-speed steel. An arc-heating method has been developed which permits continuous heating while machining, without heating the work throughout.—D. H.

The Effect of the Cutting Fluid upon Chip-Tool Interface Temperature. M. C. Shaw, J. D. Pigott, and L. P. Richardson. (Transactions of the American Society of Mechanical Engineers, 1951, vol. 73, Jan., pp. 45–56). An analysis is presented of the short-circuiting effect of a cutting fluid in conjunction with chip–tool interface temperature measurements by the tool-work thermocouple technique. An experimental arrangement based upon the results of the analysis and capable of giving reliable cutting temperatures in the presence of fluids is described. The temperature-reducing characteristics of a representative group of water-base cutting fluids are studied, and these experiments reveal that the fluids become less effective in reducing the cutting temperature as the volume of metal removed per unit time is increased. The water-base fluids considered reduce the tool-tip temperature by a cooling action to a greater extent than by a reduction of the friction force on the face of the tool.—D. H.

An Analytical Evaluation of Metal-Cutting Temperatures. K. J. Trigger and B. T. Chao. (Transactions of the American Society of Mechanical Engineers, 1951, vol. 73, Jan., pp. 57–68). The authors present a method for the determination of metal-cutting temperatures. The average tool–chip interface temperature is calculated by considering the mechanism of heat generation during metal-cutting operations in which a certain type of chip is formed. The results agree well with those obtained by other methods and the theoretical analysis has also yielded some important physical quantities and measurements which affect cutting temperatures.—D. H.

Residual Stresses in Machined Surfaces. E. K. Henriksen. (Transactions of the American Society of Mechanical Engineers, 1951, vol. 73, Jan., pp. 69–76). The stress-inducing effect of single-point tools working on steels with varying carbon content has been studied and methods for computing the stresses induced have been developed. Highly concentrated stresses (up to 100,000 lb./sq. in.) are produced. In ductile materials such as carbon steel the stresses are generally tensile, in cast iron they are compressive. Methods of investigation are described and data are given for stresses produced in various materials, by various tools, and under various cutting conditions. The possible detrimental effects of the existence of these stresses are discussed.—D. H.

Problems Connected with Changing Over to Carbide Tools. F. Taarvig. (Jernindustri, 1950, vol. 31, Apr., pp. 62–68; May, pp. 80–85). [In Norwegian]. Workshop experience with tungsten carbide tools is surveyed in Part I. In Part II the grinding of carbide tools is described. If the matrix is metal or ceramic material a weak sodium carbonate solution is recommended as a cooling medium, if the wheel is bakelite bonded the usual cooling liquid is thin oil.—B. S. E.

Tools Cast from High-Speed Steel. W. Kowalski. (Hutnik, 1951, vol. 18, Apr., pp. 160–170). [In Polish]. A discussion of problems connected with the production and uses of tools cast from high-speed steel is given.—V. G.

Electronic Apparatus for the Automatic Control of Drives for Electric Machine Tools. A. A. Bulgakov and G. N. Alyabeva. (Stanki i Instrument, 1948, No. 1, pp. 4–10). [In Russian]. The advantages of electronic controls for making machining processes automatic are considered, and a description is given of an adjustable electronic-thyratron electric drive. Performance characteristics and circuit diagrams are given of the main electronic controls.—S. K.

Grinding Holes in Cylindrical Gears. N. P. Chapaev. (Stanki i Instrument, 1948, No. 1, pp. 10–14). [In Russian]. A detailed survey is made of different designs of chuck and devices for the accurate grinding of the holes in cylindrical gears after their heat-treatment.—S. K.

Turning Austenitic Steel Type E169 with High-speed Steel Cutting Tools. N. N. Zorev. (Stanki i Instrument, 1948, No. 1, pp. 15–18). [In Russian]. An account is given of an experimental investigation to find the best conditions for the machining, on screw-cutting lathes, of two heat-resistant austenitic steels. The compositions of the steels were, respectively: C 0·52, 0·30%; Cr 13·22, 14·11%; Ni 13·75, 13·75%; and W 3·78, 2·75%. The second contained in addition 0·35% V, 0·60% Mo, and 0·08% Ti.—S. K.

On the Technology of the Production of Boring Machines. I. S. Zhegalenkov. (Stanki i Instrument, 1948, No. 1, pp. 18–20). [In Russian]. Some practical instructions are given which are said to be useful in the production of boring machines needing special accuracy.—S. K.

The Fineness of a Polished Surface. E. N. Maslov. (Stanki i Instrument, 1948, No. 1, pp. 23–24). [In Russian]. The results are presented of an experimental investigation of the factors influencing the quality of a chromium steel surface polished on a corundum wheel cooled with a 3% solution of soda. It was found that

$$H_{sq} = 4v_u^{0.6} \times s^{0.45} \times t^{0.4}$$

where H_{sq} is the mean square height of the irregularities, v_u is the speed of the specimen in m./min., t is the lateral feed in mm./pass of the table, and s is the longitudinal feed in mm./revolution of the specimen.—S. K.

A Profilometer Device for Evaluating Surface Quality. N. A. Kogan. (Stanki i Instrument, 1948, No. 1, p. 25). [In Russian]. A brief description is given of a profilometer, designed by the author, which can be used both for external and internal surfaces. The interpretation of measurements is considered.—S. K.

Pneumatic Semi-Automatic Machine for Cutting Slits in Thin-walled Parts. P. G. Belyaev and G. P. Mishurinskikh. (Stanki i Instrument, 1948, No. 1, p. 26). [In Russian]. An account is given of a semi-automatic machine which cuts simultaneously six slits in a thin-walled steel part.—S. K.

Rotating Device for Making Nuts on a Drilling Machine. N. M. Stepanov-Grebennikov. (Stanki i Instrument, 1948, No. 1, p. 27). [In Russian]. A device is described which facilitates the handling of nuts during their machining.—S. K.

Mechanization of the Production of Master Form Calibration Devices for Multiple-Cutter Copying Lathes. B. A. Shchukarev. (Stanki i Instrument, 1948, No. 2, pp. 6–11). [In Russian]. The theory is given of a method, tested in practice, for mechanizing the production of standard cams to be used in the manufacture of complicated shapes such as camshafts and crankshafts. The method enables the standards to be produced with accuracy and economy of time from data on the co-ordinates of the centres of the arcs forming the profile of the work. An account is also given of the setting up and operation of the special machine for shaping the standards. S. K.

Choosing the Type of Hard Alloy for Milling Steels. P. P. Grudov and S. I. Volkov. (Stanki i Instrument, 1948, No. 2, pp. 11–18). [In Russian]. The results are presented of a continuation of experiments on the milling of steel with hard alloy cutters of accurately determined characteristics. An alloy steel and three different hard alloys were used. The extent, rate, and nature of the wear of the cutter were determined for each alloy over a wide range of cutting speeds, the corresponding figures for optimum wear being found. S. K.

Methods of Measuring the Relief Angle of Drills and Countersinks. M. I. Babchinitser. (Stanki i Instrument, 1948, No. 2, p. 19). [In Russian]. Methods at present used for the measurement of relief angles are briefly considered and an account is given of a simple and rapid optical method.—S. K.

Universal Angle-Gauge for Drills. N. N. Atamanov. (Stanki i Instrument, 1948, No. 2, p. 21). [In Russian]. A simple instrument with angular and linear scales is described which has been found suitable for measuring various drill angles and dimensions.—S. K.

Introduction of the Use of Magnetic Plates for Securing the Parts being Machined on Milling Machines. M. I. Shalygin. (Stanki i Instrument, 1948, No. 2, pp. 21–22). [In Russian]. The reasons for the non-utilization of magnetic chucks for milling in the U.S.S.R. are discussed, and the conditions for their successful application are considered.—S. K.

Milling Cutters with Zinc Alloy Cast Bodies. A. B. Frenkel. (Stanki i Instrument, 1948, No. 2, p. 23). [In Russian]. In the method of producing milling cutters described, the teeth are arranged in a special mould, a zinc alloy of melting point 470–480° C. being poured in and allowed to solidify. When worn, the teeth can be removed by melting the alloy body.—S. K.

Cutters for Rapid Thread Cutting. P. N. Pobegalov. (Stanki i Instrument, 1948, No. 2, pp. 24–25). [In Russian]. Specially shaped roughing and finishing cutters which permit rapid thread cutting without loss of surface quality are described. S. K.

Three-Roller Self-Gripping Chuck. A. I. Flegontov. (Stanki i Instrument, 1948, No. 2, p. 25). [In Russian]. An improved design of self-gripping chuck is described in which the force is exerted by three eccentric rollers, coupled together to secure correct centring of the work.—S. K.

Pneumatic Chuck for Drilling. B. I. Tsitovskii. (Stanki i Instrument, 1948, No. 2, pp. 25–26). [In Russian]. A very brief account is given of a pneumatic air chuck, similar to those used on lathes, which has been found satisfactory for drilling machines.—S. K.

Centreless Grinding of Formed Parts. S. M. Kedrov. (Stanki i Instrument, 1948, No. 2, pp. 26–27). [In Russian]. A description is given of the grinding of bicycle parts on a centreless grinding machine of British manufacture.—S. K.

Machining of Cast Iron. H. Starck. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 161–164). Nomograms are provided to determine cutting speeds, depths, and feeds as a function of hardness of cast iron to be machined and of tool shape.—J. P.

Anneal Ductile Iron for Better Machinability. J. F. Kahles and R. Goldhoff. (Iron Age, 1950, vol. 166, Dec. 14, pp. 105–108). The authors describe experiments carried out on carbidic and pearlitic irons to correlate the influence of annealing on their physical properties and machinability. It is shown that carbide decomposition is virtually complete after 1 hr. at 1700° F. and time is reduced with increasing silicon content of the iron. For the pearlitic irons it is suggested that it is not economically worthwhile to reduce the pearlite to less than 20% due to the increased annealing time required.—A. M. F.

Super High-Speed Steels Set New Production Record. P. Leckie-Ewing. (Iron Age, 1950, vol. 166, Dec. 7, pp. 115–118). The properties and uses of high-alloy tool steels (especially with cobalt and/or vanadium) and with up to 1·5% of carbon are discussed. The red-hardness of these steels is 20–30% greater than for standard high-speed steels and they have a higher toughness than cast alloys or carbides. Another characteristic is their ability to cut most efficiently at 1½ to 2 times the feed of standard high-speed tools, but it must be remembered that as a natural corollary of their high hardness and abrasion resistance they are brittle.—A. M. F.

Machinability Depends on Microstructure. R. Le Grand. (Machinist, 1951, vol. 95, Feb. 10, pp. 191–206). This report deals with the accurate prediction of the optimum rates for machining irons and steels. It shows how the prediction depends on microstructure and processing before machining, and how microstructure also affects the selection of the tools. E. C. S.

Processes and Machines for Peeling Shafts. W. Reichel. (Stahl und Eisen, 1951, vol. 71, Feb. 15, pp. 183–193). The peeling procedure, the most economic way of turning shafts, is illustrated with reference to the design of cutting tools and to diagrams for determining their output and working speeds. The design and operation of the necessary machines, of German and American construction, are described and some suggestions are made for future developments.—J. P.

High Machinability and Productivity of Ductile Iron. J. F. Kahles, N. Zlatin, and R. B. Kropf. (Metal Progress, 1951, vol. 59, Feb., pp. 238–242). Cast iron with magnesium and spheroidal graphite constituents, maintains a high strength and acquires good machinability on annealing. Data is given on these points, and a study of the annealing process shows that it is rapid for such ductile iron. These features make it suitable for many applications, some of which are mentioned.—E. T. L.

CLEANING AND PICKLING

A Simple Test for the Cleanliness of a Metallic Surface. J. Liger. (Galvano, 1950, vol. 19, July, pp. 9–10). The acid $CuSO_4$ solution ($CuSO_4$ 30 g./litre; H_2SO_4 30 ml./litre), recommended by Hogaboom for testing for cleanliness of iron or steel surfaces, is considered insufficiently acid to dissolve thin oxide films. A solution with pH 3–4 is recommended instead.—J. P.

Conveyerized Blasting Unit Provides Economical Cleaning. V. E. Hillman. (Foundry, 1950, vol. 78, Nov., pp. 204–206). The operation of a new Wheelabrator shot-blast cleaning unit is described. The through-put of grey-iron castings was 30 to 40 tons/day.—E. J. D. S.

Sand-Blasting Machine. (Neue Giesserei, 1950, vol. 37, July 13, pp. 286–287). A description and drawing of a sand-blasting machine made by Gutmann A.G., Altona-Hamburg, is given. The machine is without a bucket conveyor and delivers the sand by means of a fan blower.—J. G. W.

Smoothing by Electropolishing and Chemical Polishing. C. L. Faust. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 137–150). The extent of levelling of metal surfaces by these two treatments as assessed by profilometer and reflectance methods is discussed. The use of these non-mechanical processes avoids the presence of stressed, flowed, or broken-up surface layers and results in better adhesion of subsequent electrodeposits. J. P.

Scale Removal Technique with the Stainless Steels. L. F. Spencer. (Steel Processing, 1950, vol. 36, Dec., pp. 623–628; 1951, vol. 37, Jan., pp. 28–30). The removal of surface oxides

and scale from stainless steels is more difficult than from plain carbon or low-alloy grades, because of the complexity of the oxides. Chemical removal by pickling can be satisfactorily carried out and no less than 11 different processes have been suggested. These include both acid and alkali solutions, and the author gives details for all 11 processes. Materials suitable for tank construction and lining are reviewed. In the second part the ferric-sulphate/hydrofluoric-acid bath is dealt with in greater detail. The performances of an experimental 100-gal. tank, and a 780-gal. commercial tank are outlined.—P. M. C.

Molten Caustic Bath Provides Rapid, Efficient Method of Cleaning Steel Parts for Painting. J. E. Fritts. (Products Finishing, 1950, vol. 15, Dec., pp. 10–18). A cleaning method for steel motor-car parts is fully described. The articles are immersed in molten caustic soda at 380–415° C. for 50 sec., rinsed in hot water, dipped in an alkaline cleaner, rinsed in cold water, and dipped in 10–13% H_3PO_4 to etch the surface and produce a light phosphate film. After a further rinsing and drying, the parts are ready to be spray-painted. The process is designed to remove drawing lubricants, but will also effectively strip the paint from parts rejected after final inspection. The parts to be treated should be so shaped that caustic soda can drain quickly.—J. P.

Hydrogen Diffusion in Steels with Varying Carbon Contents during Acid Pickling. S. A. Balezin and D. Ya. Solovei. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 75, No. 6, pp. 811–814). [In Russian]. The influence of inhibitors used in sulphuric and hydrochloric acid pickling on the rate of hydrogen diffusion through steels of varying carbon content (0·14% to 1·20%) is described.—V. G.

Evaluation of Industrial Wastes in Metal Processing Industries. D. Milne. (Metal Finishing, 1950, vol. 48, Dec., pp. 52–55, 76; 1951, vol. 49, Jan., pp. 65–69, 71). Waste solutions resulting from the operation of a comprehensive metal processing plant have been examined for their possible effects on water pollution and sewage plant activity. The prevention of loss from these wastes and suggestions for treating the undesirable wastes are discussed. It is believed that the information will serve to establish the position of the usual plant with respect to possible pollution. The need for further investigation can be established by checking operations in the plant against those described, and the management will be in a better position to discuss pollution with the enforcement authorities.—J. P.

Treatment of Spent Pickle and Washing Liquor. R. Vrijburg. (Chemisch Weekblad, 1950, vol. 46, Sept., pp. 636–638). [In Dutch]. Harmful effects of spent pickle liquor and wash water on natural waters are indicated. German methods of treatment in the Ruhr are described.—R. S.

Metal Cleaning. D. W. Vance. (Metal Finishing, 1951, vol. 49, Jan., pp. 55–57, 73). The properties of solvent, emulsion, and emulsifiable and alkaline cleaners for preparing metal for electroplating are reviewed. The application of electrocleaning and precautions to be taken in its use are described.—J. P.

Cleaning Steel Ingots and Rolled Steel. H. Rübmann. (Stahl und Eisen, 1951, vol. 71, Mar. 15, pp. 288–294). There are many ways in which the surface of steel may be freed from defects, inclusions, etc.; the method to be employed depends on individual circumstances. The equipment required is described. Planing, turning, or milling of ingots is often very necessary with alloy steels, but with low-price materials the added cost restricts their use to exceptional cases. Similarly, scarfing is used to a limited extent only. The grinding of semi-finished alloy steel can hardly be avoided. For medium and low-price steel, the use of pneumatic chisels and scarfing is being increasingly superseded by mechanical planing or grinding methods.—J. P.

Radioactive Tracers Detect Soil on Cleaned Surfaces. (Steel, 1951, vol. 128, Jan. 15, pp. 102–104). Several methods for determining surface cleanliness are described, the most sensitive being a radioactive method evolved by the Monsanto Research Laboratories. One per cent. of the tracer compound N, N-di-n-butyl stearamide is mixed with S.A.E. No. 60 oil and counts are taken before and after the cleaning process. To obtain reproducibility in evaluating the degree of cleanliness attained rigorous adherence to a standardized procedure is required.—A. M. F.

How Buick Cuts Forging Cleaning Cost. H. Chase. (Steel, 1951, vol. 128, Jan. 8, pp. 60–61). Cut shot wire has contributed to the savings realized in the blast-cleaning of automotive forging in the Buick forge shop. The parts are tumbled down an inclined drum, the blasting area having rubber-covered plate conveyors. Scale and shot drop through the perforated plates and are separated for re-use. The equipment is not too expensive and has cleaned forgings at a cost as low as 80 cents a ton at a rate of 12 tons/hr.—A. M. F.

New Process Slashes Cost of Phosphoric Acid Pickling. C. F. Paulson and M. E. Gilwood. (Iron Age, 1950, vol. 166, Dec. 14, pp. 97–99). The authors describe the main advantages that phosphoric acid has over sulphuric acid pickling. A new reclamation process now reduces the cost, which in some cases may be below that of sulphuric acid pickling. For reclamation, the acid is pumped through a cation exchange unit containing a hydrogen zeolite cation exchange resin. This resin has the property of releasing hydrogen ions and binding, in exchange, iron ions from the acid solution. The resin thus absorbs the dissolved iron from solution and simultaneously converts the iron phosphate in the pickling solution back to phosphoric acid. The exchange unit can be regenerated with sulphuric acid.—A. M. F.

Corrosion Inhibitors. G. Batta, L. Scheepers, and L. Bousmanne. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, Feb., pp. 105–115). The inhibiting action of isobutylaldehyde, alcohols, and halogen derivatives (excluding fluorides) on the solution of iron in hydrochloric acid has been studied. Theoretical considerations developed show a relation between molecular structure and the inhibiting action of organic compounds. Some practical aspects of the use of inhibitors are discussed. A. G.

Spent Pickle Liquor Recovery. Weineck. (Metall, 1951, vol. 5, Apr., pp. 154–155). Two systems for recovering spent liquor are described; they employ vacuum cooling and centrifuging, one working continuously, the other intermittently.—J. G. W.

Acid Recovery from Continuous Strip-Pickling Lines. J. Pearson and W. Bullough. (Journal of The Iron and Steel Institute, 1951, vol. 167, Apr., pp. 439–445). In a continuous strip-pickling line, acid concentrations are chosen to enable a predetermined hourly tonnage of steel to be completely freed from scale. If it is desired to incorporate an acid recovery system, so that ferrous sulphate is continuously removed from the spent pickle liquor and the free acid contained therein utilized, it is essential that the combined pickling recovery system shall be always in balance. The concentrations of acid and ferrous sulphate, and the volumes of liquor to be handled at any part of the cycle must be known in order that the correct choice of equipment may be made. This problem has been treated in a general way, so that if the acid strength requirements are specified, the other relevant information can be calculated. A numerical example is given to illustrate the use of the method. The results of determinations of the solubility of ferrous sulphate in sulphuric acid–water mixtures are given in an Appendix and an equation has been derived to enable the specific gravity of such mixtures to be calculated.

Continuous Pickling. G. Rossi Landi. (Métallurgie, 1951, vol. 83, Feb., pp. 125–127). The only useful inhibitors in continuous pickling are those which can resist up to 100° C. Special organic products, usually in powder form, are available in France. These melt at over 100° C. and boil at over 300° C. The reaction of these inhibitors with nascent hydrogen is explained.—R. S.

Washing After Descaling in Dry Galvanizing. P. Gordet. (Métallurgie, 1950, vol. 82, Oct., pp. 789–793). The reasons for washing after descaling are stated. The question of the economy of zinc is discussed in the light of Haarman's work. The author describes a series of tests on descaling and washing.

The Descaling of Metals. G. Rossi Landi. (Métallurgie, 1950, vol. 82, Oct., pp. 795–798). The trend towards sand-blasting and away from chemical descaling is noted. The technical, economic, and hygienic aspects of descaling are examined. The characteristics of inhibitors are stated.—R. S.

Efficient Use of Sandblasting Machines. A. B. Frankel. (Stanki i Instrument, 1948, No. 2, pp. 20–21). [In Russian]. The effects of increases in size of jet caused by wear, on the performance of sand-blasting machines are considered and data are given on the relationship between jet diameter and the area of surface covered with working pressures of 1–6 atm.—S. K.

XUM

Abrasive Tumbling—A Precision Finishing Method. (Steel, 1951, vol. 128, Feb. 5, pp. 81–89). The tumbling of metal parts for deburring, descaling, polishing, bright-honing and colouring, with stone chips, steel balls, and other abrasives is discussed. The choice of abrasive mixture is important and must be carefully studied for each operation. The advantages claimed for this type of finishing include the large volume of production that is possible at any one time and the fine tolerances that may be adhered to.—A. M. F.

Electrolytic Polishing of Metals. J. L. Balestrini and E. Cusi. (Maquinas e Metais, 1951, Jan., pp. 21–24). [In Spanish]. After outlining the principles of electrolytic polishing, the difficulties of current control and bath control are explained. The advantages of electrolytic polishing are: Reduction of labour, elimination of burning in stainless steels, and cheaper subsequent polishing of plated parts.—R. S.

PROTECTIVE COATINGS

The Nodule Method of Measuring the Adhesion of Electrodeposited Coatings. A. Brenner and Virginia D. Morgan. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 51–67). The surface of the electroplated article is masked except for circular areas, $\frac{1}{16}$ in. in dia. Each of these areas is surrounded by a cellulose acetate washer 0·025–0·030 in. thick. After cleaning the surface of the electrodeposit so revealed, it is plated with cobalt so as to form mushroom-shaped nodules. After the washer and masking compound have been removed, the nodules are gripped in a special chuck and the force required to detach them is measured.—J. P.

Measurement of Surface Smoothness. H. L. Kellner. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 105–124). Some of the methods of assessing surface smoothness are reviewed. These include microscopical examination of the surface and cross and taper sections, the use of stylus profilometers, film replicas, the electron microscope, and reflection methods.—J. P.

Measurement of Surface Roughness of Electrodeposited Surfaces by Means of the Microinterferometer. A. G. Strang and F. Ogburn. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 125–136). The principles of the Zeiss micro-interferometer are described. The distortion of interference fringes gives information about the surface condition of the material being examined. The methods of interpretation are illustrated by photographs which show the effect of electrodeposition, electropolishing, and mechanical finishing on the surface roughness of metals.—J. P.

The Use of Radioactive Isotopes for the Determination of Current and Metal Distribution in Electrodeposition. J. Kronsbein. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 279–288). The determination of current and metal distribution during electrodeposition requires that the deposit be everywhere of sufficient thickness for measurement. With conventional methods, this may necessitate prolonged deposition times and then polarization may alter the primary current distribution. This difficulty has been overcome by plating for short periods from an acid copper-sulphate bath containing radioactive copper Cu^{64}. The method of measuring thickness with a Geiger counter is described. The results on flat and bent cathodes show excess deposition at edges and on protruding corners and deficits in re-entrant corners, as is expected from calculations, but there is evidence even in the acid copper bath of some polarization.—J. P.

Choice of Electrodeposited Coatings. C. H. Sample. (Plating, 1950, vol. 37, June, pp. 618–624). Continuation of a previous article (*see* Journ. I. and S.I., 1951, vol. 168, July, p. 322). The corrosion behaviour, under a variety of conditions, of deposits of zinc, cadmium, chromium, lead, nickel, tin, copper, gold, and other noble metals is reviewed. The cost of applying electrodeposits is discussed briefly.—J. P.

Vacuum Coating. L. Holland. (Engineering Inspection, 1950–51, vol. 14, Winter Issue, pp. 166–175). After a brief review of the applications of vacuum coating in the electronic engineering field, the author describes in detail both the evaporation and cathode sputtering processes. Types of evaporation crucible and cathode, methods of cleaning surfaces before treatment, the influence of gas pressure on deposition rate, and many more aspects of the two processes are described, together with diagrams and details of typical equipment. It is pointed out that evaporated films of almost all metals and numerous oxides and salts can be obtained, but only certain metals have satisfactory sputtering rates. Evaporation can also produce thicker films at faster rates than sputtering. A table is also given which shows the melting points, evaporation temperatures, and suitable crucible materials for many metals, oxides, and salts. There are 34 references.—P. M. C.

The Struggle Against Corrosion and Wear of Metals by Surface Treatment. M. Ballay. (Revue Générale de Mécanique, 1950, vol. 34, July, pp. 271–277). Metallic deposits and surface treatments are described. The former include hot dipping, pistol spraying, electrolytic deposits, plating, and hard-facing. The latter include case-hardening, nitriding, Sherardizing, Calorizing, chemical and anodic oxidation, and phosphatizing. Non-metallic coatings including enamels, varnishes, paints, and plastic are briefly surveyed.—R. S.

Advances in Production Methods in Metal Finishing. A. Bregman. (Metal Progress, 1951, vol. 59, Jan., pp. 77–80E). This review of recent progress deals with metal cleaning, mechanical finishing, electroplating, waste disposal, hot galvanizing, and non-metallic finishing. In cleaning, the di-phase cleaner and the three-step compound are new, and so are the use of liquid abrasive blast and the sodium hydride descaling process. Periodic reverse plating is noteworthy, and the increase in the use of electroforming. The Sendzimir galvanizing process is a radical innovation. The main problem now is the shortage of nickel, cadmium, zinc, copper, and various chemicals.—E. T. L.

Finishing Operations on Springs. (Machinery, 1950, vol. 76, Sept. 28, pp. 61–67). The problems involved in the finishing of springs are briefly discussed under the following headings: Steel Springs; Pre-Coated Wire; Plating; Hydrogen Embrittlement; Phosphate Treatments; Shot Peenings; Non-Ferrous Springs; and Design of Springs in Relation to Subsequent Finishing.—E. C. S.

Self-Regulating High-Speed Chromium Plating. J. E. Stareck, F. Passal, and H. Mahlstedt. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 31–49). It is claimed that certain additions to a CrO_3–H_2SO_4 bath will automatically regulate the SO_4 content even over long periods in spite of sulphuric acid 'drag-in' from acid etch treatments. The modified bath has a higher cathode current efficiency, plates better on passivated nickel or chromium surfaces, and has better covering power than conventional solutions. When used for applying heavy deposits, it gives smoother coatings with greater freedom from treeing and nodules. The nature and mode of action of the additions are not disclosed.—J. P.

Participation of Chromous Chloride and Hydrogen in the Process of Thermal Chromium Plating. N. G. Klyuchnikov. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 74, No. 2, pp. 267–269). [In Russian]. On the basis of experimental evidence it is claimed that during thermal chromium plating only chromous chloride is present and the process can be conducted in the atmosphere of the latter without ferrochromium being present. Hydrogen dissolved in metals takes an active part in the process and in some cases increases the amount of deposited chromium five to ten times.—V. G.

Dichromate Reduction Rate at a Steel Surface in Air-Free Acetic Acid Solution. N. Hackerman and R. M. Hurd. (Journal of the Electrochemical Society, 1951, vol. 98, Feb., pp. 51–56). The rate of reduction of dichromate in air-free acetic acid solutions in contact with steel discs was determined as a function of time by titration and colorimetrically. There was measurable loss of dichromate in all cases except when air was deliberately introduced. In general, the rate curves became level before all the dichromate was reduced. J. P.

Bright Nickel Plating Baths. J. Salauze. (Galvano, 1950, vol. 19, Oct., pp. 11–19). The compositions and characteristics of the cobalt and organic bright nickel baths as patented and licensed by several American firms are reviewed. J. P.

Cold Galvanizing. H. Barron. (Industrial Finishing, 1951, vol. 3, Feb., pp. 543–552). The material consists of finely divided zinc powder in a binder, taken up in an appropriate solvent. The solvent evaporates leaving a film which contains about 95% of zinc. The most favoured solvents are polystyrene, isomerized rubber, and chlorinated rubber. Water absorption and water vapour transmission by these coatings are extremely low. Cold galvanizing has proved successful

when an acid- and alkali-resisting lacquer has been applied to the surface of the zinc. Both in testing and in actual use a routine test consists of removing the cold galvanized coating from a 3-in. square, inspecting the exposed surface, and then recoating the surface by cold galvanizing. Combined with the superimposed chemical resisting treatments the method has helped to solve some difficult problems.—E. T. T.

Anode Maintenance in the Alkaline Stannate Tin Plating Bath. F. A. Lowenheim. (Metal Finishing, 1951, vol. 49, Mar., pp. 60–64). Directions are given for conditioning tin anodes so that the tin dissolves in the tetravalent state, and for maintaining this condition.—J. P.

Hot-Tinning of Steel. Preparation of "Difficult" Steels. (Galvano, 1950, vol. 19, July, pp. 15–16). The use of dilute HNO_3 or dilute HNO_3–H_2SO_4 mixtures for treating difficult steels before tinning is described.—J. P.

Glass as a Coating for Steel. W. G. Martin. (Mechanical Engineering, 1951, vol. 73, Feb., pp. 109–113). Examples are given of the functional use of the glass-coating process. Some of the production troubles encountered are described with reference to the manufacture of glass-lined storage and water-heater tanks. A brief description of the process is given, with typical analyses of steels suitable for glass lining.—D. H.

Surface Protection via Phosphate Coatings. M. G. Crandell. (Canadian Metals, 1950, vol. 13, Nov., pp. 30–33, 46–47). Phosphatizing or Bonderizing of metals is described in general outline, corrosion-preventing and paint-bonding properties of phosphate coatings being stressed. Phosphatizing is also useful in the drawing of metals, the plastic and oil-retaining properties of phosphate coatings reducing friction between drawing tool and product.—E. C.

Code of Good Practice for Metallization with the Oxy-Acetylene Pistol. (Galvano, 1950, vol. 19, Sept., pp. 17–22; Oct., pp. 20–22). The Belgian Committee of the Oxy-Acetylene Industry has drawn up a code of good practice to guide and instruct metal sprayers. Details of it are given. J. P.

Phosphatization of Metals. J. Kamecki. (Hutnik, 1950, vol. 18, Mar., pp. 102–109). [In Polish]. The history of the use of phosphate treatments of metallic surfaces for protection against corrosion and methods of its application and uses in industry are described.—V. G.

Metallization by Pistol. W. F. Hedde. (Revue Générale de Mécanique, 1950, vol. 34, July, pp. 282–284). Methods of preparing the stock for spraying are mentioned, including the Cramp and Motenax processes (details are not given). The three main fields of application are: Protection; repairs; and decoration.—R. S.

Plant Control to Reduce Enamelling Rejects. J. H. Gray. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1951, vol. 90, Jan. 4, pp. 19–23). Methods reducing the failures due to the human element are discussed. These include proper supervision, the provision of suitable apparatus, regular inspection of shot-blasting equipment, regular control of pickling bath strengths, the aeration of cold hydrochloric acid tanks, a regular dip-weight test of the enamel, and a sieve list for ensuring the fineness of the enamel in the mill room. The provision of a velocity of at least 110 cu. ft./min. of air at the mouth of the spray booth should be provided, and jigs are helpful in spraying certain shapes. Attention is also drawn to the need for careful design of the dryers and furnace. A recording pyrometer should be installed on each furnace.—J. E. W.

Protection of Structural Steelwork against Corrosion: Preparation of Surfaces and Selection of Paints and other Protective Media. G. T. Colegate. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 29, pp. 1035–1041; 1951, vol. 162, Jan. 5, pp. 37–43; Jan. 12, pp. 87–93; Jan. 19, pp. 141–150). After briefly referring to the loss of steel due to corrosion and to the conditions under which it occurs, the author discusses methods of minimizing corrosion, with special reference to paints. The methods of preparing the surface are described and illustrated; these include: (1) Weathering; (2) wire-brushing, descaling, and chipping, both manually and with electrically or pneumatically operated aids; (3) pickling; (4) sand-blasting and shot-blasting; and (5) flame cleaning. The factors affecting the choice of preparation method are considered, and priming paints, including oil-base primers, zinc-rich primers, chlorinated rubber paints, and bituminous and coal-tar base paints are discussed. The limitations of the primers and the inhibiting effect of the different pigments are dealt with, and the methods of applying the primer are described. Results of tests on primers are included. Sprayed and hot-dipped metal coatings are then considered, followed by details of various types of finishing paint. Finally, the author discusses factors affecting the choice of protective system, in particular for buried steelwork, steel in contact with sea water, and the severe corrosive conditions in chemical works.—G. F.

Tanks for Electroplating Baths. O. P. Krämer. (Metall, 1951, vol. 5, Apr., p. 153). Materials for tanks for 30 electrolytes are tabulated together with suggested heating methods, composite tanks are also briefly discussed.—J. G. W.

Electroplating Rectifiers. L. W. Reinken. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 89–95). A brief review is given of the development of rectifiers both in Europe and in the U.S.A. A description is given of the copper oxide rectifier, the oldest metallic rectifier commercially used, the magnesium copper sulphide, and the selenium rectifiers. The relative advantages and disadvantages of these types are enumerated; the author suggests that the selenium rectifier will ultimately be the only type used in electroplating. The relative merits of motor generators and rectifiers are also discussed and efficiency, overload, initial cost, maintenance, life, resistance to corrosion, flexibility, and voltage control are considered. Brief rectifier specifications are given and recommendations are put forward for the benefit of purchasers and users of rectifier equipment.—M. D. J. B.

Metal Colouring. C. Harris. (Metal Industry, 1951, vol. 78, Feb. 23, pp. 143–146). The production of brown and blue temper colours by heating in air and salt baths is briefly outlined, and the formulæ and compositions of solutions used for 'gun-barrel' and chemical-black colouring are described together with details of the processes. Phosphate coatings are also briefly reviewed, and the author concludes with descriptions of hot tinning, hot galvanizing, and sherardizing. P. M. C.

Metallic and Non-Metallic Coatings for Gray Iron. C. O. Burgess. (Gray Iron Founders Society, Inc., 1951). The booklet is devoted to a survey of metallic and non-metallic coatings that have been successfully applied to grey iron on a commercial scale to meet appearance, corrosion, wear or other requirements. The section on metallic coatings deals with their application and special advantages. Spraying and hot-dipping with the alloys used are described and the materials and methods of hard-facing mentioned. Calorizing, chromizing, and sherardizing are discussed and the special advantages of electrodeposition given. Organic finishes discussed in the section on non-metallic coatings are classified and the advantages and applications of varnish-base paints, lacquers, and synthetic shellac-base paints given. The uses of vitreous and porcelain enamels are noted and oxide, phosphate, and nitride coatings described; colouring is briefly mentioned and the use of cement linings discussed. The author stresses that because of such extensive information and rapid development on each coating process, only the possibilities of each type of surface treatment and the most widely accepted method of application can be described. The bibliography has some 150 references.—D. H.

Chromium Plated Internal Combustion Engine Cylinders. J. van der Horst. (Teknisk Tidskrift, 1950, vol. 80, Apr. 22, pp. 359–364). [In Swedish]. After the electrodeposition of chromium on the inside of Diesel engine cylinders, the current is reversed to produce a surface etching of the plating. This facilitates the adhesion of an oil film which reduces wear during running. Conical anodes are used to ensure uniform chromium coating.—B. S. E.

Corrosion-Resistant Chromium Deposits. H. Silman. (Metal Industry, 1951, vol. 78, Apr. 27, pp. 327–330). Chromium deposited under conditions which differ only slightly has widely divergent properties. The author describes the effect of both temperature, current density, and deposit thickness on the hardness, structure, and corrosion resistance of chromium deposits, the latter property being considered for acid, alkali, and salt solutions. There are 16 references. P. M. C.

Spectrographic Analysis of Superficial Metallic Layers Obtained by Thermal Diffusion of Chromium in Iron and Steel. F. Malamand. (Comptes Rendus, 1951, vol. 232, Jan. 15, pp. 236–238). The process of chromizing in the vapour phase is studied by superficial spectrographic analysis, combined with electrolytic polishing, enabling 20 samples to be taken

from a depth of 0·1 mm. Results agree with that given by diffusion theory. The curves show a marked discontinuity at 13% chromium, corresponding to the γ–α phase boundary, at a depth depending on the carbon content.—A. G.

Chromium Plating of Large Drying Cylinders. A. H. Loveless. (Industrial Chemist, 1951, vol. 27, Apr., pp. 166–170). An illustrated description is given of the plant set up by the Ionic Plating Co., Ltd. for chromium plating cast-iron cylinders, 4 ft. in dia. × 10 ft. long weighing 4 tons each, used for drying sodium orthophosphates. Half a cylinder is plated at a time in the vertical position. A D.C. supply of about 20,000 amp. is provided. The anode system consists of 40 vertical bars each 4 ft. 8 in. long × 4½ in. wide × 1½ in. thick cast in 8% antimonial lead on a copper core. The prepared roll is lowered into the plating bath and the electrolyte is run in rapidly from a storage tank. The cylinder is then back etched, the current rapidly reversed and applied as a heavy striking current for 1 hr. and then dropped to plating value.—R. A. R.

The Effect of Operating Conditions on the Hardness of Chromium Plate. R. E. Howell. (Metal Finishing, 1951, vol. 49, Mar., pp. 50–56, 69). The hardest chromium deposits (Knoop hardness numbers up to 1750) are obtained at low current densities, low temperatures, and low CrO_3 concentrations. The current density is quite critical and must be controlled accurately. In the temperature range 45–50° C., a wider latitude of current density is permissible. At any temperature and concentration, the hardest plate is obtained at a current density slightly greater than that giving the brightest deposit. Apparent microhardness varies with applied load; the most suitable load should therefore be determined previously for the particular type of specimen being examined.—J. P.

Plating Stainless Steel. H. H. Head. (Metal Industry, 1951, vol. 78, Apr. 13, pp. 287–290). All the common grades of stainless steel may be covered with electrodeposits of the common metals if the surface is first activated (*i.e.*, oxide film removed). The preliminary operation of scale removal by shot-blasting, tumbling, pickling, or molten salt treatment is outlined, and polishing and cleaning methods are described. Next follow details of activation treatments using either sulphuric acid, hydrochloric acid, or nickel chloride–hydrochloric acid solutions, and the article closes with details of the techniques and solutions necessary for depositing cadmium, copper, chromium, gold, nickel, and silver.—P. M. C.

Bright Chromizing—The Onera Process. P. Galmiche. (Metal Finishing, 1951, vol. 49, Jan., pp. 61–64). A process has been developed at the Office National d'Etudes et de Recherches Aeronautiques in France in which ferrous alloys are given bright chromized surface layers. The chromizing medium is a mixture of powdered chromium, alumina, and moist ammonium fluoride (neutral or acid), or a mixture of ammonium fluoride and HF. The process is carried out in a hydrogen atmosphere. It is claimed that the ammonium fluoride reacts with the chromium to produce CrF_2 which in turn reacts with iron to give FeF_2 and chromium, and that the FeF_2 is immediately reduced by the hydrogen to reform HF and iron, so that there is no attack on the articles being treated. The HF subsequently reacts with the powdered chromium to produce more volatile CrF_2. The equipment employed is similar to that in pack carburizing and temperatures employed are of the order of 1050–1100° C. Thus mild steel gives chromized layers (Cr content > 13%) 0·004 in. thick in 3 hr. at 1050° C. and 0·01 in. thick in 6 hr. at 1100° C. The chromium content at the surface of the layers exceeds 50%. A Fe–Cr sigma phase is sometimes observed near the surface; it can be removed by a brief electropolish. The chromized layers have excellent resistance to atmospheric, salt-water, and high-temperature corrosion, to wear, and to attack by nitric acid and nitrous oxides at high temperatures. It is also claimed that the process may be used to improve the properties of 'cermets' such as alumina–molybdenum. J. P.

'Inorganic Chromatography on Cellulose: Some Applications to the Analysis of Nickel Plating Baths. F. H. Burstall, N. F. Kember, and R. A. Wells. (Journal of the Electrodepositors' Technical Society, 1951, vol. 27, Advance Copy No. 11). The estimation of cobalt, iron, copper, zinc, manganese, and cadmium in nickel sulphate plating baths can be carried out accurately by the following method. Portions of the solution (5 or 10 ml.) are evaporated to dryness and dissolved in 2 ml. of 5 *N*-HCl. This solution is absorbed on 2 g. of cellulose pulp and transferred to the top of a column prepared by packing a glass tube, 10 cm. long and 2 cm. wide, with cellulose pulp in acetone (analytical reagent) containing 2 vol.-% of 1·18-density HCl. The same acetone–acid mixture is poured through the tube in small portions, each being first used to wash the beaker in which the sample was treated. When 150 ml. of solvent have been used, the eluent is evaporated nearly to dryness and then taken again nearly to dryness with 1 ml. of $HClO_4$ and 0·5 ml. of H_2SO_4. The residue is dissolved in water and made up to 25 or 50 ml. in a graduated flask. Aliquot portions are then taken for estimation of cobalt, iron, copper, zinc, and manganese by colorimetric methods, and of cadmium polarographically, the methods being described. Nickel, chromium, aluminium, and lead remain adsorbed on the column and thus do not interfere. J. P.

Hydrogen Embrittlement in Nickel, Tin, and Lead Electroplating. C. A. Zapffe and M. E. Haslem. (Plating, 1950, vol. 37, June, pp. 610–617). On the basis of tests with several typical nickel, tin, and lead electrolytes, by a method already described (*see* Journ. I. and S.I., 1951, vol. 168, July, p. 322) it is concluded that mild steel is relatively insensitive to embrittlement by hydrogen during plating, whereas stainless steel is particularly sensitive. The conventional Watts nickel bath shows less embrittlement than any yet studied, except a dilute fluoborate solution. Addition of brightening and anti-pitting agents to this nickel bath increased embrittlement. Acid stannous sulphate plating causes about the same embrittlement as acid zinc and acid copper processes. Alkaline tin plating causes embrittlement of mild steel, exceeding that observed in any process, and of stainless steel, virtually identical with that from cyanide plating and cathodic pickling. Hydrogen peroxide added to the alkaline tin bath has no effect on embrittlement. A concentrated fluoborate lead bath causes fairly severe hydrogen pick-up with short plating times which, however, decreases on prolonged deposition. J. P.

Electroplating. P. Bang. (Dansk Teknisk Tidsskrift, 1950, vol. 74, Apr., pp. 112–115: Jernindustri, 1950, vol. 31, Sept., pp. 154–156; Oct., pp. 171–172). [In Norwegian]. The conventional theoretical outline of electroplating is presented, and examples of electrolytic zinc coating applications are given. The purity of the electrodeposited zinc is of great importance for the corrosion protection; a coating 18 μ thick is equivalent at least to a 36 μ layer obtained by hot dipping. B. S. E.

Protection of Galvanizing Baths. (Galvano, 1950, vol. 19, Aug., pp. 15–17). The methods by which galvanizing baths may be protected so that operatives do not fall therein or get splashed by molten metal and the precautions taken at a number of works are described.—J. P.

Zinc Plating. (Electrical Review, 1951, vol. 148, Apr. 20, pp. 785–789). The construction and operation of two full-scale continuous electroplating plants recently installed by British Coated Sheets, Ltd., Ellesmere, for the production of zinc-coated steel sheets is described. Each plant can deposit zinc from 0·00005 to 0·0003 in. or more and operating continuously has an output of 2–2½ tons/hr.—D. H.

Metallography of Electro-Tinplate. J. E. Davies and W. E. Hoare. (Journal of The Iron and Steel Institute, 1951, vol. 168, June, pp. 134–140). Samples of electro-tinplate from seven different sources have been examined by two metallographic techniques—oblique cross-sectioning and surface examination after de-tinning. Suitable methods of preparation of micro-specimens have been developed. A tin–iron compound layer identified as $FeSn_2$, has been observed in all flow-brightened samples. Study of commercial samples and laboratory-produced specimens indicates that the general crystallographic appearance of the tin–iron compound depends on the temperature reached in flow-brightening, on the time elapsing between fusing and quenching, and also on the orientation of the underlying ferrite grains.

The Electrodeposition of Bright Tin–Nickel Alloy Plate. N. Parkinson. (Journal of the Electrodepositors' Society, 1951, vol. 27, Advance Copy No. 4). A process for the deposition of a new bright alloy coating of tin and nickel is described. The preferred electrolyte is: stannous chloride, 50 g., nickel chloride 300 g., sodium fluoride 28 g., ammonium

bifluoride, 35 g. per litre. At a working temperature of 65° C. and an average current density of 25 amp./sq. ft., bright plating is obtained over irregular objects at a current efficiency of approximately 100%. The composition of the deposit is almost independent of the current density, temperature, and content of either metal in solution. The chief factor controlling the composition of the deposit is the total fluorine content of the electrolyte. The broadest bright plating range is obtained at high temperatures and the presence of free HF and an alkali metal (preferably sodium) is necessary for best results. Anodes may be of alloy or of tin and nickel, supplied at different voltages. The alloy plate is an intermetallic compound, approximately 65/35 tin–nickel. It has a pleasing appearance and in some lights exhibits a faint rose-pink cast. The plate is extremely resistant to atmospheric tarnishing.—J. P.

An X-Ray Study of Tin–Nickel Electrodeposits. H. P. Rooksby. (Journal of the Electrodepositors' Technical Society, 1951, vol. 27, Advance Copy No. 5). An X-ray study is reported of the crystal structure and textural properties of the tin–nickel electrodeposits prepared by the process described by N. Parkinson (*see* previous abstract). A metastable nickel arsenide type structure, similar to that of γ'-Ni_3Sn_2, characterizes the deposits. The hexagonal cell constants $a_0 = 4{\cdot}15$ Å., $c_0 = 5{\cdot}10$ Å, $c/a = 1{\cdot}23$ differ appreciably from established values for Ni_3Sn_2 and the differences result from the change in composition from Ni_3Sn_2 towards NiSn induced by the conditions of electrodeposition. The alloy is stable up to 300° C., but decomposes on heating above this temperature. A strongly marked preferred orientation texture is found in bright tin–nickel deposits and an analogy with bright speculum is evident.—J. P.

Molybdenum Plating—Answer to Lower Cost Metals for High Temperature Service? (Steel, 1951, vol. 128, Jan. 8, pp. 62–64). Molybdenum plating of steel has been carried out experimentally by the hydrogen reduction of molybdenum pentachloride. Three types of structure were found, fine-grained, coarse-grained, and laminated, depending on the temperature and pressure used. An intermediate layer of nickel or copper–nickel gave a better bond due to the reduction in the formation of intermetallic compounds.—A. M. F.

Copper Plating of Iron and Steel, and Nickel Plating of Copper, Brass and Bronze. R. Zirilli. (Pro-Metal, 1951, pp. 778–792; Apr., pp. 811–820). A detailed description is given of the technology of copper and nickel plating of certain metals as practised in modern industry. The descriptions include: methods of cleaning articles, types of plating bath, and finishing procedure.—J. J.

The Strength and Ductility of Electrodeposited Metals. II—Some Data on Acid Copper Deposits. T. A. Prater and H. J. Read. (Plating, 1950, vol. 37, Aug., pp. 830–834, 850). Experimental work on electrodeposited copper sheet to test the reproducibility of the hydraulic bulge test (*see* Journ. I. and S.I., 1951, vol. 168, July, p. 322) is reported. Because of the difficulty in obtaining specimens which could be assumed to be identical, it is taken that reproducibility is satisfactory because the significant-stress/significant-strain data from each specimen fall on smooth curves which are similar to those obtained in the conventional tensile test. Best agreement between duplicate tests was obtained on the thinner sheets, probably because of more uniform thickness. No effect of thickness on the stress/strain curve was observed in the range 0·00066–0·0036 in. The occurrence of some anisotropy was attributed to the direction of burnishing of the lead rolls on which the sheet was deposited. This anisotropy did not affect seriously the validity of the bulge test method.—J. P.

Repairing Steel, Cast Iron, Copper, Copper Alloys, Aluminium and Light Alloy Castings by Metallization. M. Cauchetier. (Fonderie, 1951, Mar., pp. 2385–2391). Types of metallization pistols and the properties of the projected metals are described. Some hints on machining are given. Methods of improving adhesion are mentioned. Applications of metallization include making complete metal moulds or making moulds partly by metallizing and then casting on to the metallized shape; repair of cracks; and metallizing parts which have to be inserted in moulds for casting metals of a different quality.—R. S.

The Metallurgy of Metal Spraying. K. Krekeler. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 340–342). Metal spraying is described and microphotographs are given showing grain size, impurities, and adhesion of zinc-sprayed layers.—U. E.

How to Protect Your Steel. J. B. Scott. (Chemical Engineering, 1951, vol. 58, Apr., pp. 135–138). The atmospheric conditions, combined with the fumes associated with the manufacture of $(NH_4)_2SO_4$, severely attack steel structures at the Adams Terminal Plant of Phillips Chemical Co., Pasadena, Tex. Surface preparation before protection is important. Dry sand blasting is best, and the protective coating should be applied as soon as possible. A quick drying or single application coating reduces inter-coating contamination, which causes peeling. Phenolic, alkyd, asphalt and coal tar, Gilsonite-asphalt, and vinyl coatings have been tried with varying success depending on environment, but chemical resistance of the coating is not as important as low porosity. An electronic film-thickness gauge and the use of a two-colour system aided good coverage. Short lengths of angle iron are better test pieces than panels, since most failures occur at corners and thin edges.—T. E. D.

Reduction in Plating Cost by the Use of Flat-Polished and Phosphate-Coated Steel. H. J. McVey and V. M. Darsey. (Proceedings of the 37th Annual Convention, American Electroplaters' Society, 1950, pp. 251–255). Flat-polishing of steel is more economical than polishing after forming. To protect polished steel surfaces, a phosphate coating with a suitable lubricant is used to prevent the formation of scratches and other surface defects during forming operations. Automobile bumpers are being produced by this procedure and the economies resulting from this method of manufacture suggest its application to other electroplated articles.—J. P.

Heat Resistant Ceramic Coatings Permit Substitutes for Critical Materials. D. G. Bennett. (Materials and Methods, 1951, vol. 33, Mar., pp. 65–67). Recently developed ceramic coatings make possible the use of low-alloy iron and low-carbon steel at operating temperatures much higher than normally possible. They also provide additional protection, and thereby prolong the useful life of heat-resistant alloys operating at conventional temperatures. Such coats consist of two layers; a base coat to protect the metal from the corrosive effects of oxygen or products of combustion, and a top coat consisting mainly of refractory crystalline material. This latter coat absorbs and reflects some of the radiant energy which falls upon it. Many applications of these ceramic coats are described briefly, and the importance of the choice of the properties of the coat with respect to those of the underlying metal are discussed.—P. M. C.

Metallurgical Influences in the Enamelling of Cast Iron. A. Königer. (Neue Giesserei, 1950, vol. 37, Apr. 6, pp. 125–136; Apr. 20, pp. 148–157; May 4, pp. 168–176). After a review of the extent and economic significance of defective enamelling on cast iron, the processes of production and preparation of the castings are examined. Corrosion or the occurrence of rust spots on the cast surface is one evident cause of defects and this was studied. Corrosion and enamelling defects show a close correlation with the graphite formation, which in turn is connected with the type and distribution of sulphide inclusions. The skin of castings was found to be richer in sulphur than the interior, owing partly to segregation in the molten state and partly to the introduction of sulphurous gases from the moulding sand. The formation of graphite in compact clusters in the surface material was found to be accompanied by local sulphide accumulations. During firing of the enamel the sulphide breaks down, releasing sulphur, and the escaping gaseous reaction products cause blowholes and similar defects in the enamel. The local sulphide accumulation at graphite clusters can be avoided if the conditions for producing dense castings with fine graphite are fulfilled. The sulphur content can be reduced by soda treatment, and sulphide segregation is minimized by a high casting temperature.—H. R. M.

A New Anti-Corrosion Lacquer. Iu. V. Vodzinskii. (Stanki i Instrument, 1948, No. 2, p. 25). [In Russian]. For the protection of metal parts in transit a lacquer with the following composition by weight has been found satisfactory: Nitro-dyes, 35%; rosin, 20%; drying oil, 5%; acetone, 40%. The lacquer has good covering and adhesive properties with respect to metals, the drying time being 5–6 hr. In tests the coating remained hard at 95° C., and gave complete protection during immersion in water at 15–25° C. for two months, in acid and alkali solutions for two weeks, and during

two months' exposure in the open. The lacquer is easily removed with acetone.—S. K.

X-Ray Diffraction Study of the Oxidation Characteristics of Nickel-Pickled Sheet Iron as Related to Enamel Adherence. G. S. Douglas and J. M. Zander. (Journal of the American Ceramic Society, 1951, vol. 34, No. 2, Feb. 1, pp. 52–59). Results are given of investigations, by X-ray diffraction, of the effects of nickel pickling on oxidation of bare enamelling iron, and on oxidation reactions underneath ground-coat enamels. Fe_3O_4 and FeO were found to form on the steel surface during heating, but after fusion of the enamel any Fe_3O_4 present is converted to FeO. The oxide layer was found to be taken into solution by the enamel, rate of solution decreasing as saturation is approached. Nickel pickling reduced the amount of oxide formed underneath the enamel, thus reducing the time required for complete oxide removal and improving time or temperature conditions for good adherence of a high-temperature ground coat. Improved adherence of a low-temperature ground coat may be partly due to reduced corrosion of the steel by the enamel resulting from nickel treatment. Two metallic phases, probably alloys, were found at the enamel–iron interface. A theory concerning adherence between enamel and steel is postulated, assuming sharing of oxygen atoms between the two after removal of the oxide layer.—E. C.

POWDER METALLURGY

Recent Developments in Powder Metallurgy. A. M. Butta. (Rivista di Meccanica, 1950, vol. 1, Dec. 15, pp. 11–15; 1951, vol. 2, Jan. 25, pp. 15–18). [In Italian]. After a brief review of the technique and development of powder metallurgy, the author describes the latest achievements of the process with particular reference to Italian industry.

M. D. J. B.

Designing Dies for Powdered-Metal Parts. E. Mosthaf. (Machinery, 1950, vol. 77, Aug. 24, pp. 227–233). The article draws attention to some of the basic considerations in the design of dies for pressing powdered metals.—E. C. S.

Powder-Metallurgical Studies. II—The Compressibility of Iron Powders. J. Heuberger. (Acta Polytechnica, 1950, No. 98, pp. 11–20). [In German]. It is shown that the relationship between pressure P and bulk density D of an iron powder compact can be expressed by the equation

$$k.P = \log \frac{D_\infty - a}{D_\infty - D}$$

where D_∞ has a different value according to the specific gravity ρ of the compacted metal and at high pressures approaches the bulk density of the compact ($D_\infty < \rho$), a is the apparent density of the powder, and k a proportionality factor.—R. A. R.

Microstructure of Iron–Silicon Alloys as Developed by the Powder Metallurgy Process. R. Wachtell. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 354–360; Journal of Metals, 1950, Feb.). A series of photomicrographs is presented illustrating part of the diffusion process occurring in iron–silicon compacts. The metallographic characteristics of such alloys are discussed, and various misleading pseudomorphic structures observed in the microscopic investigation are described. An etching procedure which indicates the silicon content within certain ranges is outlined.—G. F.

Powder Metallurgical Processes. IV—(*b*) Refractory Metals; (*c*) Hard Metals; (*d*) Special Materials for Electric Contacts; (*e*) Magnetic Materials; (*f*) Friction and Abrasive Materials; (*g*) Normal Metals. (Revista de Ciencia Aplicada, 1950, vol. 4, July–Aug., pp. 324–332; Sept.–Oct., pp. 403–416). [In Spanish]. Melting points and densities of refractory metals, and their chemical behaviour and uses are considered. The phases and structural changes which take place in powder-metallurgy processes are described. The manufacture of carbides, and methods of crushing and sintering are discussed.

R. S.

Report on Powder Metallurgy. T. A. Dickson. (Steel Processing, 1950, vol. 36, Dec., pp. 619–621). This is a brief review of the many desirable features of powder-metallurgy methods of producing small components.—P. M. C.

Properties of Hard Metals. W. Tofaute and J. Hinnüber. (Instituto del Hierro y del Acero, 1950, vol. 3, Oct.–Dec., pp. 261–269). [In Spanish]. After discussing the composition of sintered hard metals, the author classifies them into those with and without titanium carbide. Methods for avoiding cracks due to welding and machining stresses are described. The strength, modulus of elasticity, and resistance to heat, oxidation, and corrosion of hard metals are surveyed.—R. S.

Electrolytic Precipitation of Metal Powders. G. Wranglén. (Teknisk Tidskrift, 1949, vol. 79, Sept. 10, pp. 593–599). [In Swedish]. Two main factors govern the powder formation by precipitation, namely, concentration decrease and presence of hydroxides in the cathodic film. Examples of electrolytic methods of obtaining powders on a technical scale are supplied.

B. S. E.

Diffusion Phenomena in Sintered Metals. G. Zapf. (Metaux–Corrosion–Industries, 1951, vol. 26, Jan., pp. 10–19). A review of the work done in recent years on the rôle of diffusion in sintering of metals is given. The physical and chemical methods employed in preparing sinters are discussed, the case of copper–steel sinters in some detail. Diffusion provides the only means for homogenizing sintered metals. Recent work has shown that sintering begins and terminates by surface- and self-diffusion respectively. The strength of sintered metals also depends upon self-diffusion. If self-diffusion is hampered by impurities the strength is impaired. Carbon and oxygen are most harmful.—P. F.

New Sintered Carbides for High Output. F. Kölbl. (Betrieb und Fertigung, 1950, vol. 4, Nov., pp. 185–186). The historical development of sintered carbides for cutting tools and other purposes is briefly reviewed, and reference is made, without giving any details of composition or production, to new heat-resistant carbides and their possible uses.—H. R. M.

Hard-Metal Rock Drills. H. Steiner. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Nov., pp. 205–217). The article summarizes the experience with tungsten carbide rock drills gained by the author since 1935. After a short historical introduction the properties (hardness, breaking strength, resistance to abrasion, thermal expansion, thermal conductivity) and methods of manufacture of hard metals based on tungsten carbide are described. The design of hard-metal bits, and the performance of such bits as compared with steel bits, are discussed at length. Comparative figures are quoted from practice.—O. H. G.

Investigation of the Strength of Sintered Iron Powder as a Function of Shape. G. Bierett and T. Hövel. (Stahl und Eisen, 1951, vol. 71, Jan. 18, pp. 77–82). The behaviour of this material under non-uniform static stress has been clarified by tensile tests on sintered rings made from various grades of powder and different pressing loads. Besides indicating the general properties of sintered iron compacts, the results showed that the material was more susceptible to failure at stress concentrations than steel, but the use of correct grain size and pressing load may be expected to counteract this defect.—J. P.

PROPERTIES AND TESTS

The Significance of Mechanical Testing. E. W. Blumer. (Australian Institute of Metals: Australasian Engineer, 1951, Jan. 8, pp. 65–69). The author describes the standard tensile, impact, and bend tests. The effect of testing procedure, specimen size and shape, and temperature are considered, and the significance of the results from such tests, to a design engineer, are discussed.—P. M. C.

The Influence of the Position of Alloying Elements in the Periodic Table on Mechanical Properties of Metals. B. B. Gulyaev. (Doklady Akademii Nauk. U.S.S.R., 1950, vol. 75, No. 1, pp. 25–28). [In Russian].

The Influence of Graphite, and Especially Its Form, on Young's Modulus and the Displacement of the Neutral Plane in Bend Tests. U. von Hummel and E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 77–82). The influence of the form of graphite in cast iron on the stress-strain relationship during bending has been investigated. This relationship was characterized by the values of the contraction and notch effects, which can be readily determined. For a fixed amount of graphite, Young's modulus is progressively reduced as the graphite becomes coarser. For a given sample of cast iron the notch effect, *i.e.*, the ratio of the permanent to total strain, is a linear function of stress and for a given stress the notch effect increases as the graphite becomes coarser. The application of strain

gauges to the specimens undergoing bending has shown that the neutral plane shifts away from the mid-plane by an amount depending on the stress and the form of the graphite, and that for all samples examined, the shift was a linear function of the notch effect.—J. P.

Torsional Vibrations. L. Varriale. (Rivista di Meccanica, 1950, vol. 1, Nov. 1, pp. 5–8, Dec. 1, pp. 11–13; Dec. 15, pp. 17–20). [In Italian]. The author gives a clear exposition of the phenomena resulting from torsional vibrations. The subject is treated simply and mathematical analysis is only referred to. Oxidations, resonance, damping, and interference are considered.—M. D. J. B.

Room Temperature Tensile Tests as an Index of Transition Temperature of Steel Plates. S. S. Tör, R. D. Stout, and B. G. Johnston. (Welding Journal, 1950, vol. 29, Sept., pp. 477s–483s). Steel plates of specification A.S.T.M. A-201 (A) aluminium-killed and A-285 rimmed 1¼ and ⅝ in. thick were studied. It was found that with round bars a straight-line relationship exists between room-temperature tensile test results and transition temperatures as determined by the Lehigh and Kinzel slow-notch-bend tests and the Charpy methods. The possibility of using room-temperature tensile tests to predict the transition temperature of pressure-vessel steels has been indicated.—U. E.

Notch Impact Test at Low Temperatures. (Report Nos. 2, 3, 4 of the Netherlands Institute of Welding). (Lastechniek, 1950, vol. 16, Apr., pp. 63–65; May, pp. 79–81; June, pp. 99–104). [In Dutch]. In connection with the determination of weldability, impact tests were carried out at low temperatures with different types of test piece. The cooling apparatus for several test pieces is described. The change in temperature was measured between the moment of removal from the cooling bath and the impact. Bars which had the notch covered with wadding were cooled to − 40° C. and showed no increase in temperature within 10 sec. after removal from the bath. Temperature curves for bars cooled to − 20°, − 40°, or − 60° C. show two distinct phases: In the first 6–8 sec. there is practically no rise in temperature; in the second period there is a more rapid rise in temperature and the rate of increase is greater the lower the temperature to which the bars were cooled. In the first period the heat intake was solely by radiation and convection from the air. When the bar is in contact with the anvil, there is heat transfer through the metal. Thus, heat from each end of the bar reaches the middle section in 6–8 sec. Within this period there is little rise in temperature in bars cooled down to − 60° C. Impact test bars of normalized killed 0·13% carbon steel were tested. The type of fracture was considered in relation to testing temperature. The radius of cut notches increases more rapidly than that of pressed notches with tool wear. The degree of plastic deformation around the notch was determined by hardness measurements. This plastic deformation was not as deep in the case of cut notches but was greater in the immediate vicinity of the notch, compared with pressed notches. These phenomena had no measurable effect on the impact values.—R. S.

Effect of Ferrite Grain Structure upon Impact Properties of 0·80 Pct Carbon Spheroidite. M. Baeyertz, W. F. Craig, jun., and E. S. Bumps. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1465–1471; Journal of Metals, 1950, Dec.). The authors describe an investigation made to determine the effect of ferrite grain size and shape on the impact properties of a spheroidized steel containing 0·77% C, 0·36% Mn, 0·007% P, 0·011% S, 0·32% Si, and 1·03% Ni. The spheroidized structures were produced so that the carbide particle size and spacing were similar, by tempering the martensite produced from three different austenite grain sizes, and by subcritical annealing of pearlite. The three spheroidized structures produced from martensite were essentially similar and had almost identical impact properties, but their small uniform non-equiaxed ferrite grain structures gave considerably lower notched-bar impact transition temperatures than the larger equiaxed grain structure obtained from pearlite. The authors believe that this uniform structure derived from martensite explains the consistently good performance of unembrittled tempered martensite in notched-bar impact tests.—G. F.

The Mechanical Resistance of Metals. F. Mazzoleni. (Rivista di Meccanica, 1950, vol. 1, Oct. 15, pp. 5–10). [In Italian]. An explanation is given of the internal mechanism by which metals resist external forces. The author shows how the internal structure governs the physical behaviour of metals.—M. D. J. B.

On the Mechanisms of Rupture of Metals. G. A. Homès and J. Gouzou. (Mémoires du Centre National de Recherches Métallurgiques, 1950, Dec., pp. 19–34). Test pieces of zinc and mild steel were observed by cinematograph micro- and macro-photographs during tensile rupture. X-ray diffraction pattern photographs were also taken, and the behaviour of the two materials was compared. Three different mechanisms were postulated: (*a*) Pure cleavage; (*b*) cleavage accompanied by tearing; and (*c*) translational slip followed by tearing. (*a*) and (*b*) are always observed in zinc broken cold, but (*c*) generally occurs in mild steel. Twinning only plays a secondary rôle in the rupture process, but the importance of heterogeneity is emphasized. Intercrystalline rupture is not observed in either metal. The possibilities of translational slip are much greater in mild steel than in zinc, and cold drawing encourages sliding, which ends in intercrystalline rupture. After appreciable work-hardening, the phenomena are sometimes complicated by the hardening of zones between the grains.—T. E. D.

The Application of Photo-Elasticity in Mechanical Design. A. Mondina. (Rivista di Meccanica, 1950, vol. 1, Oct. 1, pp. 9–13). [In Italian]. The author briefly reviews the photo-elastic method of stress analysis and shows the practical applications of photo-elasticity in facilitating and improving the design of machine components. Photo-elastic analysis is particularly valuable in finding the flow of stresses in parts too complex to analyse by mathematical methods. The fundamental principles of natural and polarized light and refraction are explained and details are given of the experimental technique of photo-elastic stress measurement.

M. D. J. B.

Strain Gauges. A. L. Biermasz. (Lastechniek, 1950, vol. 16, Oct., pp. 152–156). [In Dutch]. The relation between stress and strain is explained. The principles of the strain gauge are described. Two applications of the strain gauge are discussed: (1) A break in a stone wall; and (2) the strains transmitted to the tool of a lathe.—R. S.

The Electrical Wire Resistance Strain Gauge and Its Applications. F. C. Widdis. (Machinery, 1950, vol. 77, Aug. 31, pp. 259–264). In 1937 Simmons, at the California Institute of Technology, introduced the bonded wire resistance strain gauge. Its operation is based upon the fact that certain alloys, notably cupro-nickel, show a linear change in resistance with strain. The gauge is described.—E. C. S.

Bars in Torsion. W. W. Soroka. (Machine Design, 1950, vol. 22, July, pp. 120–124). The techniques by which a designer may study torsional shear stress distributions in uniform bars of arbitrary cross-section, are discussed. The methods include numerical iteration procedure, electrical resistance networks, electrically conducting sheets, membranes, the hydrodynamic simulator, and a three-dimensional photo-elastic stress freezing method.—E. C. S.

Impact Tests of Welded Austenitic Stainless Steels. V. N. Krivobok and R. D. Thomas, jun. (Welding Journal, 1950, vol. 29, Sept., pp. 493s–495s). Impact data on plates and weld metal of 15 different types are tabulated. The specimens were tested in the annealed, stress-relieved, and as-welded conditions. No conclusions are drawn.—U. E.

Manual on Fatigue Testing. (American Society for Testing Materials, 1949, Special Technical Publication No. 91, p. 82). The purpose of the manual is to supply information to those setting up new laboratory facilities, to aid in properly operating the equipment, and to offer advice on presentation and interpretation of the data. The chapter headings are: Introduction; Symbols and Nomenclature for Fatigue Testing; Fatigue Testing Machines; Specimens and Their Preparation; Test Procedure and Technique; Presentation of Fatigue Data; Interpretation of Fatigue Data; and Bibliography.

J. B. B.

The Influence of Surface-Active Substances on Fatigue of Steel. G. V. Karpenko. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 6, pp. 1225–1228). [In Russian]. Surface-active substances to a considerable degree lower the fatigue limit of quenched steel, and to a lesser degree of raw steel.

V. G.

The Influence of Shape in the Resistance to Fatigue of Mechanical Parts. L. Locati. (Rivista di Meccanica, 1950, vol. 1, Sept. 15, pp. 11–14). [In Italian]. The influence of

shape and design on fatigue failures is examined. The author shows how a knowledge of the flow of stresses in machine parts is the best guarantee against fatigue. A brief description is given of the nature of fatigue in metals and a table of shape coefficients is established on both theoretical and experimental grounds.—M. D. J. B.

Shot Peening and Its Application to Steel Springs. A. G. Ligier. (Revue Générale de Mécanique, 1950, vol. 34, Oct., pp. 365–369). Well-known American work on the effect of shot-peening on fatigue strength is mentioned. The Almen method of determining the effects of shot-peening by measuring the deformation of a thin steel strip shot-peened on one side, is described. The principles of the 'Airless' and 'Air-blast' types of machine are stated. Details are given of endurance limits in relation to peening. Finally there is a note on surface rolling and pressing.—R. S.

The Influence of Biaxiality on Notch Brittleness. D. Rosenthal and W. D. Mitchell. (Welding Journal, 1950, vol. 29, Sept., pp. 409s–421s). The embrittlement of a notch, or the so-called notch sensitivity in flat mild-steel specimens subjected to tension and bending has been investigated by ascertaining the ductility transition temperature. The thickness of the specimen, depth, and radius of the notch were studied. The value of the stress-concentration factor at the bottom of the notch was kept constant. This factor is defined as the ratio of the actual stress at the bottom of the notch to the stress which would have existed at this point in the absence of the notch. It was found that, as the specimens became thinner, the transition temperature approached the same value regardless of the depth and radius of notch. As the specimens were made thicker, the deeper notches gave higher transition temperatures than the more shallow ones despite the same value of stress-concentration factor. It was concluded that the combined increase of thickness of specimen and depth of notch created a triaxial stress field below the surface of the notch and that the degree of triaxiality of this field was the major factor responsible for the notch sensitivity.—U. E.

Stresses Around a Spot Weld under Static and Cyclic Loads. G. Welter. (Welding Journal, 1950, vol. 29, Nov., pp. 565s–576s). The exact distribution of the stresses around the spot, as measured at the outside surface of the sheet, has been studied as a function of the applied static tension loads. A new type of measurement taken at the interface of the spot welds was made. A number of fatigue tests of untreated and hydrostatically improved specimens of mild steel, stainless steel, and 24 ST Alclad alloy sheets has been carried out. At the outside surface around the spot compression stresses were observed. Slight tensile stresses were measured at a small distance above the spot in the axis of the joint. Test results concerning the development of fatigue cracks under cyclic tension load showed that these cracks start at the interface of the weld, due to repeated bending of the sheet in a zone close to the spot. Hydrostatically treated spots have a 25–50% higher fatigue limit than untreated points.—U. E.

The Hardness and Strength of Metals. D. Tabor. (Journal of the Institute of Metals, 1951, vol. 79, Mar., pp. 1–18). The theory of hardness measuring is discussed and it is shown that indentation hardness measurements are essentially a measure of the elastic limit of the metal. For metals which do not work-harden appreciably the hardness value for both the Brinell and the Vickers indenter is approximately three times the yield stress. The indentation process itself produces an increase in the yield stress of metals which work-harden appreciably. It is possible to deduce the true and the nominal stress–strain curves, and the ultimate tensile strength of a metal from its Brinell hardness number and its Meyer index. A series of curves is drawn showing the variation in the ultimate-tensile-strength/Brinell-hardness ratio with the Meyer index, and it is shown that materials as diverse as tool steel, work-hardened nickel, and annealed copper all lie near the theoretical curves.—R. A. R.

The Micro-Mechanism of Fracture in the Tension-Impact Test. W. H. Bruckner. (Welding Journal, 1950, vol. 29, Sept., pp. 467s–476s). A metallographic study was made of specimens of rimmed semi-killed and fully killed steels and of Armco iron which were partially fractured or loaded almost to fracture. It was found that the tension impact fracture in the transition temperature range for all the steels tested was initially in the carbide lamellæ. Cleavage fracture may be the result of (*a*) pearlite fracture, and (*b*) mechanical twinning in the region of high stress at the cracks and finally cleavage. The killed steels showed an outstanding difference from the rimmed and semi-killed steels in the reluctance of the mechanical twins to propagate across the ferrite grains from one grain boundary to the other. For the rimmed and semi-killed steels the twinning usually extended over the entire grain diameter. The higher twin-nucleation temperature which the less thoroughly deoxidized steels possess is considered to be the chief factor responsible for their more easily produced cleavage fracture.—U. E.

New Process Checks Hardness Electronically. C. Rieker. (Machinist, 1950, vol. 94, Dec. 16, pp. 1818–1820). The hardness tester depends on the fact that magnetic retentivity is a function of the hardness in ferrous metals and that the harder the casting the more magnetic lines of force it will retain when magnetized by a constant force. This automatic electronic device increases production and eliminates human errors in non-destructive testing heat-treated ferrous materials.

E. C. S.

Some Factors Affecting Microhardness Values. B. B. Hundy. (Metallurgia, 1951, vol. 43, Feb., pp. 99–102). The author's own experimental results concerning the factors affecting microhardness values, obtained using two types of 'balanced beam' tester, are correlated with the results of other workers. The importance of the various factors is discussed, and the precautions necessary to give reproducible results are listed.—J. B. B.

The Electrostatic Component of the Force of Friction. R. Schnurmann. (British Rheologists' Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 62–68). Experimental evidence has previously been presented in support of the view that jerky motion of a frictional contact operated at a uniform rate of propulsion was of electrostatic origin. The author presents direct experimental evidence, illustrating with the aid of a cathode-ray oscilloscope, the electrification of frictional contacts. With a metallic friction element loaded against a rotating steel disc, rapid oscillations were obtained at linear speeds of several hundred centimetres per second. Similar phenomena were obtained on substituting a rotating glass disc.—J. A. L.

Physical Changes in Rubbing Surfaces on Scuffing. D. Clayton and C. H. M. Jenkins. (British Rheologists' Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 69–77). Cast-iron surfaces rubbing against steel have been found to develop a thin layer of a white constituent when scuffing occurs or is approached. This paper consists of the collection of results of the microscopical examination of the physical condition of surfaces after scuffing. The white constituent appears to have a basis of two phases, cementite and a quenched high-carbon ferritic phase developed from austenite, resulting from the high temperature developed by rubbing.—J. A. L.

An Investigation of Surface Damage Using Radioactive Metals. E. Rabinowicz. (British Rheologists' Club and Institute of Physics Symposium on Physics of Lubrication: British Journal of Applied Physics, 1951, Supplement No. 1, pp. 82–85). This paper describes experiments in which a radioactive metal hemisphere slides over a non-radioactive metal surface, and the amount and nature of the transferred material are examined autoradiographically. It is found that metal transfer takes place in the form of discrete fragments, and that well-lubricated surfaces give less transfer than clean surfaces by factors of 400 or more. It is found also that the coefficient of friction and the metal transfer increase markedly at the melting point of the surface film, the metal transfer moreover being sensitive to temperature changes below this melting point.—J. A. L.

Inspection of Crane Hooks by the Magnetic Particle Method. M. B. Graham. (Non-Destructive Testing, 1950, vol. 9, Autumn Issue, pp. 9, 10). Repeated rubbing or peening of the bearing surface by wire ropes and chains may form layers of brittle, cold-worked metal, which eventually crack and lead to sudden failure of heavy crane hooks. The author describes how such cracks may be detected by passing direct electric current laterally through the hook, while iron powder is sprayed on to the surface. An annealing treatment for removing these hard, layers before cracking occurs, is described.—P. M. C.

White Fluid for Magnetic Crack Detection. (Machinery, 1950, vol. 77, Aug. 10, pp. 183–184). When a fluid consisting of a thin oil vehicle, *e.g.*, paraffin, and a suspension of magnetic iron-oxide particles are washed over the surface of a magnetized article, the particles collect in discontinuities and indicate their position. Metropolitan-Vickers Electrical Co., Ltd., have developed a white fluid for this purpose. Equal parts by volume of iron oxide and aluminium, ground in a ball mill, make a good suspension for this purpose.—E. C. S.

Inspection of Factory Materials. J. J. Vistalli. (Ingenieria e Industria, 1950, vol. 18, July, pp. 70–71). [In Spanish]. This is a brief note on magnetic crack detection, as practised in the U.S.A.—R. S.

New Non-Destructive Methods of Testing and Their Principles. F. Förster. (Metall, 1951, vol. 5, Jan., pp. 20–21). The following methods are briefly mentioned. Magnetic powder method, crack detection with the aid of an oscilloscope, 'magnetography,' eddy current method, and high-frequency induction coil.—J. G. W.

Effect of Annealing in a Magnetic Field upon Iron–Cobalt and Iron–Cobalt–Nickel Alloys Prepared by Powder Metallurgy. J. F. Libsch, E. Both, G. W. Beckmann, D. Warren, and R. J. Franklin. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 287–296; Journal of Metals, 1950, Feb.). Optimum retentivity and minimum coercive force after magnetic annealing are shown to occur in the binary alloy at a cobalt concentration of approximately 50%, the alloy exhibiting an essentially rectangular hysteresis loop when subjected to the best magnetic annealing cycle developed. The addition of nickel up to 10% is detrimental to these optimum properties, and although further addition up to 80% decreases the coercive force sharply, the saturation and retentivity remain considerably inferior to those of the binary alloy containing 50% Co.—G. F.

Magnetic Materials. R. de Lucas Ortueta and E. Yuste Garrido. (Revista de Ciencia Aplicada, 1950, vol. 4, July–Aug., pp. 289–300; Sept.–Oct., pp. 428–439; Nov.–Dec., pp. 495–506). [In Spanish]. The main properties of modern magnetic materials, their applications, and methods of measuring their properties are described. These materials are classified and their molecular constitutions are studied. The different types of loss are considered. The effects of impurities and the methods of stress-relieving are discussed. The manufacture of materials for permanent magnets by fusion and synthetic methods and the development of such properties as permeability and coercive force and the increased intensity of magnetization are examined. Finally, methods of measuring magnetic properties are described.—R. S.

The Thermoelastic Effect in Iron and Nickel as a Function of Temperature. R. Rocca and M. B. Bever. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 327–333; Journal of Metals, 1950, Feb.). The adiabatic thermo-elastic temperature change has been determined in nickel and Armco iron as a function of temperature and of change in stress, the results being in agreement with the equation first derived by Kelvin. Near the Curie temperature, the thermo-elastic effect is found to change appreciably, and calculations confirm that the thermal expansion coefficient of iron decreases in the vicinity of the Curie temperature, as predicted by the theory of ferromagnetism. An equation for the adiabatic thermo-elastic temperature change is derived.—G. F.

Suggested New Approach to the Mechanism and Effects of Solution Treatment and Ageing on Metal-Alloy Wires and Strip. C. P. Bernhoeft. (Wire Industry, 1951, vol. 18, Apr., pp. 371–377). Avogadro's hypothesis and number are used to calculate the free space of action available for each molecule and to determine the density of elements. It is shown why, in chemical combinations, the volume is sometimes smaller than the total volume of the single reacting volumes. This loss of volume is taken as the basis for a suggested new approach to the explanation of the mechanism and effects of chilling and solution treatment and ageing on ferrous and non-ferrous metals and alloys, as used in the manufacture of wire and strip. It is, in fact, suggested that the shrinkage consequent upon certain chemical combinations gives rise to stresses which account for altered physical properties.

J. G. W.

Contributions to the Data on Theoretical Metallurgy. XI—Entropies of Inorganic Substances. Revision (1948) of Data and Methods of Calculation. K. K. Kelly. (United States Bureau of Mines, 1950, Bulletin No. 477). Examples are given of five different methods for calculating entropies. An extensive list of the entropies of inorganic substances at 298·16° K. is given together with data concerning changes in state. The bulletin concludes with a bibliography citing 517 references.—B. G. B.

Flaw Detection with Supersonic Waves. R. Brown. (Canadian Metals, 1950, vol. 13, Dec., pp. 24–25, 29). A general account is given of the use of the Supersonic Echo Sounder for non-destructive detection of hair-line cracks and other internal defects in metals. Finished or unfinished parts may be tested and thickness can be measured from one surface.—E. C.

Ultrasonic Wave Propagation in Materials: a Guide to Theoretical Results. L. Gold. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 3–13). A non-mathematical dissertation on ultrasonic wave propagation in materials is presented under the following headings: General Wave Properties; Generation and Detection of Ultrasonic Waves; Types and Velocities of Ultrasonic Waves; and Energy Aspects of Ultrasonics.—J. B. B.

Inspection, Processing, and Manufacturing Control of Metals by Ultrasonic Methods. C. H. Hastings and S. W. Carter. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 14–61). Pioneer work in the field of ultrasonics is reviewed, and the various types of generator are described. Applications to the following fields are outlined: Powder metallurgy; grain-size refinement; acceleration of solidification; alloying; heat-treating; fatigue testing; plating, bonding, and tinning; and degassing of melts. The theoretical background, necessary apparatus, and techniques used for the detection of discontinuities in metals are described in some detail, and the application of ultrasonics to several specific cases is given. There are 342 references.

J. B. B.

Basic Principles of Ultrasonic Testing. J. C. Smack. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 62–71). This is a review which includes progress in the instrumentation for ultrasonic testing of metals, the available equipment, its principle of operation and its application, including the setting up of test standards.—J. B. B.

Ultrasonics in the Heavy Forging Industry. J. C. Hartley. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 72–83). The application of the non-destructive ultrasonic testing to the detection and location of cracks and similar internal defects in heavy forgings is described.—J. B. B.

Ultrasonic Testing in Railroad Work. E. D. Hall. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 87–89). The use of ultrasonic testing has enabled the Erie Railroad to detect fatigue cracks in the driving axles of steam locomotives without removing the wheels from the axle. Instead of an arbitrary mileage limit, the axles are now allowed to run until they are too worn or show a defective condition by the ultrasonic method.—J. B. B.

Ultrasonics in the Electrical Industry. D. M. Kelman. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 90–101). The Westinghouse Electric Corporation utilizes ultrasonic testing to detect flaws in many of their products and raw materials. Examination of large turbo-generator rotor forgings and of the bonding between babbitt metal and steel is described.—J. B. B.

Pulse Techniques Applied to Dynamic Testing. J. R. Leslie. (American Society for Testing Materials, 1951, Special Technical Publication No. 101, pp. 104–113). Many of the difficulties of dynamic testing can be overcome by measuring the velocity of propagation of an acoustical pulse through the material to be tested. The pulse velocity so obtained is independent of the size and shape of the specimen, and the elastic modulus can be calculated using one simple formula for all cases. An electronic pulse adjusted for use in testing concrete structures in the field is described.—J. B. B.

Gamma-Radiography in Shipbuilding and Engineering. J. D. Hislop. (Transactions of the Institute of Marine Engineers, 1951, vol. 63, May, pp. 83–96). Within the past twelve months there have been several new developments in the practice of gamma-radiography, the most important of these being the ease with which artificial radioactive sub-

stances have become available from the Atomic Energy Research Establishment at Harwell. The introduction of three sources for industrial work, cobalt, tantalum, and iridium, has rendered the use of radium obsolete (although radon is still a very useful source in some cases), and has made desirable a review of the principles, and present practice, of gamma-radiography in Great Britain. This paper describes gamma-radiographic technique and application, and indicates the factors which govern the choice of a suitable source. The problem of the safe handling of sources and of personnel protection is discussed, and some indication of the cost of gamma-radiography is given.

The Use of Radioactive Isotopes in Industrial Radiography. G. H. Tenney. (Non-Destructive Testing, 1950, vol. 9, Autumn Issue, pp. 6–8). The literature is reviewed, and the production of isotopes is discussed briefly. The best type of isotope is analysed from the standpoint of industrial radiography, and a table giving gamma energies and half-lives for eight isotopes is included. Cobalt-60 is a satisfactory source for steel and for materials of higher atomic numbers, whilst iridium-192, with its lower emitting energy, is suitable for radiographing light metals. The effect of specific activity (source strength) on the quality of radiographs is also referred to. There are 13 references.—P. M. C.

Radioactivity Units and Radiography. A. I. Berman. (Non-Destructive Testing, 1950, vol. 9, Autumn Issue, pp. 11–15). Much confusion exists in the fields employing radioactive isotopes, because none of the many unofficial definitions of the unit of radioactive source strength, the curie, has gained universal approval. Furthermore, this unit has come to mean something entirely different in various radiographic installations, namely, a measure of gamma-ray intensity. The author reviews several definitions of the curie, together with an alternative unit for describing the source strength of those radioisotopes which emit gamma rays. This unit is 'roentgen per hour at one metre (rhm).' A proposal is also introduced for comparing the quality of gamma-radiation from different sources, in order to meet the requirements of industrial radiography.—P. M. C.

Radiologic Safety in Radiography with Isotopes. T. N. White. (Non-Destructive Testing, 1950, vol. 9, Autumn Issue, pp. 19–22). The article covers in a rather general way the main radiologic safety problems encountered in the use of radium and radioactive isotopes in radiography. An appendix includes some detailed information on maximum permissible exposure for the human body, and data for approximate exposure rate calculations. There are 20 references.—P. M. C.

Fracture under Combined Stress Creep Conditions of a 0·5 per Cent Mo Steel. A. E. Johnson and N. E. Frost. (National Physical Laboratory: Engineer, 1951, vol. 191, Apr. 6, pp. 434–437). A description is given of pure tension, pure torsion, and combined stress creep tests made on a 0·5% Mo steel at a temperature of 550° C., to examine the validity of the Siegfried hypothesis of fracture under combined stress creep conditions, and to establish a criterion of fracture. It is found that the results obtained cannot be explained upon the basis of the Siegfried criterion, and that the criterion of fracture is apparently the maximum principal stress. All creep curves examined have a form given by the general equation: Creep strain $= C(K_1 t + At^n) + Be^{K_2 t}$, where t is time and K_1, A, n, B, K_2, and C are constants.—M. D. J. B.

Microscopical Examination of Creep Specimens. E. A. Jenkinson. (Engineer, 1951, vol. 191, Apr. 13, pp. 469–472). This article forms an appendix to the article 'Fracture under Combined Stress Creep Conditions of a 0·5% Mo Steel' by A. E. Johnston and N. E. Frost (*see* preceding abstract). A description is given of the solid and tubular 0·5% molybdenum steel test specimens. Detailed results are given of the tensile creep tests at 550° C. carried out on solid specimens and of the tensile and torsion stresses imposed on tubular specimens. Photomicrographs are given of the material before and after fracture.—M. D. J. B.

The Relationship between Criteria of Second Region of Relaxation and Creep of Austenitic Steel. I. A. Oding. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 75, No. 2, pp. 197–200). [In Russian]. A theory combining the creep velocity with relaxation was developed and confirmed by experimental data obtained on creep and relaxation for four different heat-resistant austenitic steels.—V. G.

The Influence of Niobium Additions on Creep of Heat-Resistant Austenitic Chromium Nickel Steel. A. M. Borozdyka. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 75, No. 2, pp. 213–214). [In Russian]. The influence of niobium on creep of heat-resistant steels was investigated. Results showed that niobium can replace tungsten as an alloying element in this steel.—V. G.

Investigations into the Embrittlement of Ferritic Stainless Steel at 475° C. C. A. Zapffe, C. O. Worden, and R. L. Phebus. (Stahl und Eisen, 1951, vol. 71, Feb. 1, pp. 109–119). To investigate the embrittlement of ferritic stainless steels at 475° C., bend tests and high-magnification fractographic examinations were conducted on steels with 17, 21, and 26% chromium. The bend tests were performed with plain and notched specimens in a special apparatus; embrittled notched specimens showed bend angles of only 1·5–2° before fracture. The fractographs gave information about the course of the fracture, and the crystallographic characteristics of tough and embrittled specimens, and elucidated the influence of impact velocity, pre-annealing of the steel at 850–1200° C., and the temperature of the fracture (20, 475, and − 196° C.). Sensitivity to embrittlement increased with increasing chromium content and the temperature of maximum embrittlement lay nearer 500° C. than 475° C. The fracture of embrittled steel was transcrystalline, occurred on the $\{100\}$ cleavage planes, and showed no marked difference from similar cleavages in non-embrittled steel. Occasionally, however, fractured surfaces were intercrystalline and were veined or folded as a result of an impressed phase. The appearance suggested a similarity to the intercrystalline oxide phase in molybdenum.—J. P.

Fundamental Concepts, Experimental Data, and Recent Work on Creep. E. Morlet. (Revue Générale de Mécanique, 1950, vol. 34, July, pp. 251–258). [In French]. The following different types of mechanical deformation are discussed: Elastic, quasi-elastic, plastic, and viscous deformation with and without cold work. Deformation as a function of time and temperature is discussed. Creep curves are explained and methods of determining rates of creep are indicated.—R. S.

The Influence of Microstructure and Chemical Composition on the Creep Resistance of Chromium–Molybdenum Steels. G. Delbart and M. Ravery. (Comptes Rendus, 1951, vol. 232, Jan. 3, pp. 67–69). Previous work on a steel *C* (C 0·12%, Cr 0·6%, Mo 0·6%) is extended to two steels of higher carbon content (*A*, C 0·31%, Cr 2·0%, Mo 0·48%; and *B*, C 0·53%, Mo 0·44%). At 450° C. with a load of 20 kg./sq. mm.: (1) Creep rates for steel *A* in the pearlitic and bainitic states were in the ratio 15 : 1 while under the same conditions steel *C* gave a value of 30; (2) steels *A* and *C* in the bainitic condition were identical; and (3) steels *A* and *C* in the pearlitic condition had creep rates in the ratio 3 : 1. These results show structure to be far more important than composition in determining creep resistance.—A. G.

Some Effects of Phosphorus and Nitrogen on the Properties of Low Carbon Steel. G. H. Enzian. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 346–353; Journal of Metals, 1950, Feb.). A study of the tensile and impact properties, strain-sensitivity, and strain-ageing of a number of low-carbon induction furnace heats containing varying amounts of phosphorus (up to 0·14%) and nitrogen (up to 0·014%), is made. The results indicate that, with the exception of strain-ageing behaviour, the two elements exert additive effects, so that the content of each element must be known in order to evaluate the significance of a change in either element. In the absence of aluminium deoxidation, variation of either element alone has the greatest effect on the properties of the steel when the content of the other element is relatively low.—G. F.

The Effect of Nitrogen on Brittle Behaviour of Mild Steels. G. H. Enzian and G. J. Salvaggio. (Welding Journal, 1950, vol. 29, Nov., pp. 537s–544s). Investigation of the brittle behaviour of mild-steel plates has shown that the effect of nitrogen may not be as pronounced as previously indicated. Several steelmaking and processing variables exert considerable influence on this behaviour, and these must be considered in evaluating the significance of variations in nitrogen content. In steels with low Mn/C ratios little or no change in brittle behaviour was found with nitrogen variations within the range normally obtained by various open-hearth practices. Steels with higher Mn/C ratios exhibited, in general, somewhat

better properties, but these were more susceptible to variation with change in nitrogen content. Some interesting observations are made concerning comparisons of tests and criteria used to determine transition temperature. A good correlation was found between transition temperature and sensitivity to cold work.—U. E.

Contribution to the Study of the Influence of Hydrogen on the Ductility of Steel. F. Meunier and A. Demarez. (Mémoires du Centre National de Recherches Métallurgiques, 1950, Dec., pp. 5–10). Experiments, in which samples of mild steel from a basic electric arc furnace were charged with hydrogen by soaking in dilute HCl, and then heat-treated to liberate the hydrogen, showed that the hydrogen was present in two states: (*a*) That which diffused easily, and (*b*) that which diffused with difficulty. Further recharging of a degassed sample showed that progressively more hydrogen was taken up in the form (*b*) with each recharging, until an upper limit was reached. This indicated that fresh discontinuities were being formed within the crystals with each recharging. The ductility, which is decreased by the presence of hydrogen, was found to be dependent on the concentration of hydrogen in the form (*b*). The mechanical properties of the steel could be improved by heating for 1 hr. at 680° C., or 48 hr. at 200° C. This treatment does not eliminate the hydrogen, but redistributes it in a more favourable state.—T. E. D.

The Influence of Amplitude and Speed of Plastic Deformation on the Segregation of Hydrogen in Iron and Steel. P. Bastien and P. Azou. (Comptes Rendus, 1951, vol. 232, Jan. 3, pp. 69–71). Test pieces previously charged with hydrogen were ruptured in tension in times varying from 0·066 sec. to 140 min. At high speeds the effect of hydrogen was slight; it rose to a maximum for times between 10 sec. and 30 min. and then progressively diminished. Impact tests showed hydrogen to have no effect without preliminary plastic deformation. This presumably allows 'proton' hydrogen to segregate in faults and set up tri-axial stresses causing brittleness. This segregation cannot occur at high speeds of testing nor at sufficiently low temperatures (hydrogen brittleness disappears at − 110° C.) while at very slow speeds diffusion of the molecular hydrogen can take place.—A. G.

The Effect of Hydrogen on the Brittle Strength of a Series of Steels. G. L. Hopkin and D. O. Pickman. (Armament Research Establishment Report No. 10/50, Ministry of Supply, Feb., 1951). The effect of hydrogen on the strength properties of a series of steels has been investigated. The notch tensile test was used to produce a triaxial stress condition. Hydrogen caused a marked reduction in the brittle strength of hardened low-alloy chromium–molybdenum, manganese–molybdenum, and nickel–chromium–molybdenum steels, but the effect on a low-carbon steel was slight. The use of different strain rates and testing temperatures has shown that the deleterious effect of hydrogen on intercrystalline cohesion only becomes significant when conditions are such that diffusion of hydrogen can readily take place. The reduction in brittle strength is explained by the diffusion of hydrogen to certain preferential grain-boundary sites where it accumulates under pressure.

The Choice of Steels for Engineering Purposes. A. Bellini. (Rivista di Meccanica, 1951, vol. 2, Feb. 25, pp. 4–10). [In Italian]. The influence of nickel, chromium, molybdenum, manganese, silicon, vanadium, aluminium, sulphur, and phosphorus on the mechanical properties, elastic deformation, resistance to fatigue, corrosion, heat, and workability of steels is discussed, and it is shown how to use this information in the selection of a steel for service under particular conditions.
M. D. J. B.

Manufacture and Properties of Low-Nitrogen Bessemer Steels. III—Mechanical Tests. L. Marbais and M. Nepper. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 30–35). Tests on compression hardening, work hardening, ageing, bending, blue brittleness, and impact properties were made and the behaviour in drawing, hot rolling, and cold rolling studied. Oxygen enrichment improves quality and, used with steam, gives nitrogen contents below 0·003%, the steels being equal to open-hearth qualities for wire and thin strip.—A. G.

Manufacture and Properties of Low-Nitrogen Bessemer Steels. IV—Second Statistical Study of the Influence of the Constituents of Total Analysis on the Mechanical Properties of Thin Sheets. M. Nepper and L. Dor. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 35–46). A statistical study using punched cards was made of (*a*) normal Bessemer steel (nitrogen 0·009%); (*b*) oxygen enrichment with ore additions (nitrogen 0·004%); and (*c*) oxygen-steam blast (nitrogen 0·003%). Annealed tensile strength depends mainly on phosphorus when the nitrogen falls below 0·003% and at this low value nitrogen has no effect on the hardness as annealed or on work hardening.
A. G.

Influence of the Elements on the Properties of Steels and Cast Irons. J. Vazquez Lopez. (Anales de Mecanica y Electricidad, 1950, vol. 26, Nov.–Dec., pp. 322–330). [In Spanish]. The paper deals with the influence of wolfram in increasing tensile strength and hardness at high temperatures. The effect of uranium is also briefly described.—R. S.

The Effects of Molybdenum and Commercial Ranges of Phosphorus upon the Toughness of Manganese Steels Containing 0·40% Carbon. M. Baeyertz, W. F. Craig, jun., and J. P. Sheehan. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 389–396; Journal of Metals, 1950, Feb.). A description is given of an investigation into the effects of molybdenum and phosphorus on the toughness of A.I.S.I.-S.A.E. 1340 manganese steels containing 0·40% carbon, a series of heats at phosphorus levels varying from 0·010% to 0·035% being made, with molybdenum increasing from 0·003% to 0·35% and simultaneous decrease in manganese from 1·90% to 0·82%. The replacement of manganese by molybdenum in amounts necessary to maintain the hardenability of the molybdenum-free steel is shown to counteract the detrimental effects of phosphorus to a marked degree. With 0·18% molybdenum, toughness was virtually unaffected by severe embrittling treatments, even with a phosphorus content of 0·035%.—G. F.

Interchangeability of Cb and Ta in Type 347 Stainless. W. O. Binder. (Metal Progress, 1951, vol. 59, Feb., pp. 219–227). Columbium prevents intergranular corrosion in stainless steel, but owing to the demand for columbium it is necessary to find a substitute. Tantalum is suitable, although this is equivalent to only half the quantity of columbium, and about 1·6% of tantalum is needed. The ratio of columbium equivalent to carbon content is about ten. Stainless tantalum-treated steels were found satisfactory in withstanding high-temperature corrosion, for welding, and as regards high-temperature strength.—E. T. L.

The Effect of Boron on Cast Iron. (National Bureau of Standards: Canadian Metals, 1950, vol. 13, Dec., pp. 26, 28). Results of foundry experiments with boron additions to cast iron are reported in brief. Boron was found to increase the depth of chill of cast iron as well as its hardness. Size and quantity of graphite particles were decreased and the free carbide content increased. An undercooling effect was produced, becoming more pronounced with increasing boron additions.—E. C.

Influence of Increased Silicon or Manganese Content on the Properties of 10- and 14-ton Basic Open-Hearth Forging Ingots. W. Meisemeyer. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 8–15). An investigation has been conducted into the structure, segregation, inclusions, and mechanical properties of heat-treated blocks cut from 10- and 14-ton ingots of basic open-hearth steel with increased manganese and normal silicon contents and increased silicon and normal manganese contents. The silicon steel had the following advantages: (1) Finer primary crystallization; (2) smaller tendency to segregation of sulphur and carbon in the upper portion of the ingot; (3) greater uniformity of mechanical properties and absence of conchoidal and fibrous fractures; and (4) reduced danger of flaking. The increased deoxidation of the silicon steel was the reason for the first three of these advantages. The higher yield point of the high-silicon steel in the non-heat-treated condition may be of importance in simplifying heat-treatment.—J. P.

Alternate Steels Useful as Substitutes for Critical Materials. E. L. Cady. (Materials and Methods, 1951, vol. 33, Jan., pp. 62, 63). With the American defence effort rapidly expanding, the leaner NE (National Emergency) steels, now called Tentative Standards, are again proving valuable as replacements for scarce alloy grades. The recommended alternatives for several standard grades are listed.—P. M. C.

Identification of Stainless Steels. J. C. Codoni. (Ingenieria e Industria, 1950, vol. 18, Nov.–Dec., pp. 88–90, 108). [In

XUM

Spanish]. A system is described which enables stainless steel to be distinguished from other qualities and 15 types of corrosion-resisting steels to be separated. A solution of 5% copper sulphate in water is used. Steels other than stainless are coated with copper. Other tests include nitric acid (to separate stainless from alloys such as monel); magnetic tests; hydrochloric acid test (to distinguish machinable austenitic qualities); scaling tests; phosphoric acid tests (to separate Cr–Ni from Cr–Ni–Mo types); and stabilization tests (to separate the niobium or titanium stabilized austenitic qualities from the straight 18/8).—R. S.

Stainless Steels: Improved Resistance to Sulphuric Acid. (Iron and Steel, 1950, vol. 23, July, pp. 309–311). A short account is given of the research work at Brown Bayley Steels, Ltd., resulting in the production of a stainless steel which is resistant to sulphuric acid of any concentration at temperatures up to 40° C. The steel contains 18% Cr, 18% Ni, 2% Cu, and 2% Mo, and was developed from the well-known 18/8 stainless steel.—G. F.

A Study of Cast-Iron Rolls. I. Sans Darnis. (Revista de Ciencia Aplicada, 1950, vol. 4, July–Aug., pp. 301–313). [In Spanish]. Cast-iron rolls are classified into two groups, according to their surfaces. Two practical cases of sand-cast rolls and chilled rolls are illustrated by micrographs. Details of analysis and hardness are discussed in relation to the manufacturing technique.—R. S.

Nodular Cast Iron: Heat Treatment and Physical Properties. R. Y. Scapple. (Iron and Steel, 1950, vol. 23, Sept.–Oct.–Nov., pp. 379–382). The author gives the results of investigations carried out on a magnesium-treated nodular cast iron to determine the effect of heat-treatment on the structure and physical properties. Heating to below the A_1 line causes graphitization, whilst above the A_1 line solution of graphite occurs. The hardness values of specimens quenched in oil from below the A_1 line are roughly a function of combined carbon content, and quenching from above the A_1 line gives a martensitic structure. The impact values of quenched specimens increases with tempering temperature, and annealed specimens show a relatively high toughness.—G. F.

Cast Iron with Nodular Graphite as a Material of Construction. A. Wittmoser. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Jan. 21, pp. 49–57). This is a comprehensive survey of the mechanical properties of nodular cast iron, in the light of which its possible uses in engineering construction are examined. The data include results of the author's own experiments, but in the main are based on British and American literature. Nodular cast iron is compared with grey cast iron, Meehanite, cast steel, and structural steel.—J. G. W.

Steel Bolts—Determining Permissible External Axial Loads. A. Brunner. (Machine Design, 1950, vol. 22, June, pp. 124–127). Tables, which cover a large percentage of bolt uses with sufficient accuracy to be of considerable value to the machine designer, are developed by restricting the data to steel bolts and studs, assembled without special lubrication, and loaded axially without bending or shear stresses imposed by the load.—E. C. S.

The Effect of Brake Shoe Action on Thermal Cracking and on Failure of Wrought Steel Railway Car Wheels. H. R. Wetenkamp, O. M. Sidebottom, and H. J. Schrader. (University of Illinois, 1950, Engineering Experiment Station Bulletin Series No. 387). A comprehensive investigation is reported of the manner in which heat-treatment, wheel design, carbon content, and method of wheel manufacture affect the ability of wrought steel wheels to resist fracture and thermal cracks. In general, rim-quenched wheels with residual compressive stresses were more resistant to fracture than oil-quenched wheels with tensile stresses predominating in the ring. Lowering the carbon content from 0·72 to 0·61% slightly increased the resistance to fracture.—R. A. R.

Creep of Materials. A. Johansson. (Teknisk Tidskrift, 1949, vol. 79, Feb. 19, pp. 127–133). [In Swedish]. Some experiences with various materials used in turbines are related. The abnormal creep in carbon steels depends on imperfect deoxidation in the steelmaking process especially with aluminium addition beyond the critical amount. Creep as a function of temperature variations is emphasized and the types of creep-testing machine developed in Sweden are described.—B. S. E.

Choice of Metallic Materials for High Temperatures. A. Hultgren. (Teknisk Tidskrift, 1949, vol. 79, Feb. 19, pp. 117–126). [In Swedish]. The strength properties of metals at normal temperatures are reviewed, and composition modifications to achieve alloys resisting oxidation at high temperatures are generalized. British, American, and German examples as employed in gas turbines are presented.—B. S. E.

Swedish Steels for High-Pressure Steam. H. Nathorst. (Teknisk Tidskrift, 1949, vol. 79, Dec. 31, pp. 1012–1014). [In Swedish]. Experiences relating to graphite formation in welded tube joints indicate that steels of the chromium–molybdenum–vanadium type are safer for high-pressure steam tubes than the chromium-free English type. The tubes are not only required to be resistant to corrosion, but also to attack by hydrogen generated from the steam. Titanium or niobium stabilized chromium–nickel steels are likely to be resistant to hydrogen attack on the carbide particles. Strength properties at room temperature aid in the judgment of workability. Creep tests indicate that the surface condition of the tubes is important.—B. S. E.

Influence of Certain Alloying Elements on the Properties at High Temperatures of Austenitic Chromium–Manganese Steels of the 18–10 Type. T. Murakami and T. Koinumaru. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1949, vol. 6, Nov.–Dec., pp. 489–497). (This is translated from Tetsu to Hagane, 1948, vol. 34, July, pp. 10–13). Graphs are given of the influences of carbon, silicon, aluminium, copper, molybdenum, and tungsten on the tensile strength elongation, Charpy resilience, plasticity, and resistances to oxidation, at various temperatures, of these steels, which had been held at 1100° C. for 30 min. and air-cooled.—N. MCE.

Development and Present Status of Wrought Heat-Resistant Rolled and Forged Steels. K. Bungardt. (Stahl und Eisen, 1951, vol. 71, Mar. 15, pp. 273–281). Heat-resistant steels are iron alloys with high structural stability, resistance to scaling, and adequate mechanical properties at temperatures above about 600° C. Depending on their application, they must also possess good mechanical strength at room temperature and satisfactory weldability and machinability. The development of these steels before 1939 was along the lines of increasing use of alloy additions, such as chromium, nickel, manganese, and tungsten. A limited success was achieved during the war in meeting shortages by making heat-resistant ferritic chromium–silicon or chromium–aluminium–silicon and austenitic chromium–manganese–silicon steels, though there is now a tendency to return to the older proved types. In spite of continued investigation, embrittlement of heat-resistant steels is still unexplained.—J. P.

Influence of a Notch on the Strength of Steel at High Temperatures. M. I. Kurmanov and R. S. Kaplan. (Zavodskaya Laboratoriya: Hutnické Listy, 1951, vol. 6, Mar., pp. 148–149). [In Czech]. The authors investigated the influence of notches on the strength of steels stressed at 500° and 550° C. for long periods. Two low-alloy steels were used (40 Kh N with C 0·41%, Ni 0·65%, Cr 0·022%, and EI-10 with C 0·31%, Ni 1·17%, Mo 0·35%, V 0·15%). The results do not confirm the view held by some authors that additions of nickel increase the tendency of steel to hot shortness and its sensitivity to notches. Notch sensitivity appears to be influenced not only by the tendency to hot shortness, but also by the ratio of the strengths of the steel within the grains and at the grain boundaries. The grain substance of the EI-10 steel has a higher strength than the boundary substance (owing to the presence of molybdenum and vanadium carbides) and plastic deformation consists therefore of intergranular creep. At 550° C. the notch sensitivity increases rapidly owing to increased exhaustion of the plasticity of the grain boundaries, which is also indicated by lower contraction values. Carbide-forming elements are absent in the 40 Kh N steel, thus deformation occurs inside the grains. This steel has therefore a lower notch sensitivity.—E. G.

Safety Margins and Stress Levels in High-Temperature Equipment. E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, vol. 73, Jan., pp. 89–99). The author reviews the factors of safety and working stress levels now used in high-temperature equipment and discusses their relationship to physical properties at high temperature as determined by modern test methods. The rules adopted by the author's company (the General Electric Company) are discussed.

High-Alloy Weldments for Heat- and Corrosion-Resistant Applications. P. Goetcheus. (Industrial Heating, 1950, vol.

17, Oct., pp. 1762–1772 ; Nov., pp. 1928–1932). In the first part the author discusses the use of rolled alloys in fabricated heat-resistant equipment for use at high temperatures. New developments in alloys and designs are included. In the second part information is given on the welding of high-alloy castings for heat- and corrosion-resistant applications.
J. A. L.

Jet Engine Parts Studied at New G-E Laboratory. (Steel, 1950, vol. 127, Dec. 18, pp. 98–99). A brief description is given of the new laboratory of the General Electric Co. where jet-engine parts can be studied at simulated altitudes of 70,000 ft. and at temperatures of — 100° F.—A. M. F.

Advances in High-Temperature Strain Gauges and Their Application to the Measurement of Vibratory Stresses in Hollow Turbine Blades during Engine Operation. R. H. Kemp, W. C. Morgan, and S. S. Manson. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 209–228). An improved high-temperature wire-resistance strain gauge has been developed for use at temperatures up to 1500° F. and at frequencies up to 10,800 cycles/sec. The wire was either ' Karma ' or 80/20 platinum–iridium. Full details are given of the construction, attachment, calibration, and properties of these gauges, and the experimental procedure and results obtained for tests on hollow turbine blades during the actual operation of a turbojet engine are given.—P. M. C.

A High-Speed, High-Temperature Precision Testing Machine for Gas Turbine Disk Research. A. C. Hagg, B. Cametti, and G. O. Sankey. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 17–28). A machine has been designed in which disc specimens up to 14 in. in dia. and 2 in. thick can be rotated at speeds up to 35,000 r.p.m. and at temperatures up to 1500° F. The temperature may be uniform or arranged for radial gradients in the discs of up to 100° F./in. Plastic and creep strains are measured over the disc surfaces in radial and tangential directions by utilizing punch-marked spacings. Specimen temperature is continuously measured and recorded using thermocouple circuits with slip-ring coupling. Full details are given of machine construction and experimental procedure.

Bursting Tests of Rotating Disks Typical of Small Gas Turbine Design. W. E. Skidmore. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 29–48). Discs 8 in. in dia. have been tested to destruction by rotating at speeds approaching 100,000 r.p.m. Yield speed, bursting speed, and elongation data were obtained at room temperature for 14ST aluminium and SAE 4130 steel discs. The effect of profile, centrally located holes, and blade loading on the above properties was investigated. The results, when compared with static tensile properties, indicated that theoretical elastic stresses are not always a definite criterion of failure. Maximum calculated stresses in discs with central holes were as high as 200% of tensile strength at bursting. Central holes reduced bursting speeds in proportion to the section area removed, and all specimens, regardless of shape, burst at average stresses approximately 10% below the material tensile strength.—P. M. C.

METALLOGRAPHY

Contribution to the Definition of Microstructure by Means of a Metallographic Atlas. F. Roll. (Metall, 1950, vol. 4, Nov., pp. 463–466). The author pleads for the use of a metallographic atlas containing photographs of certain standard microstructures, as a means of rapid identification and brief description of various structures, particularly of cast metals and alloys. Photographs of eight structures of manganese steel as cast, and of six structures of the same steel after heat-treatment serve to illustrate the idea.—J. G. W.

Accuracy of Measurement in X-Ray Studies of Microstructure. F. Gunther. (Die Technik, 1951, vol. 6, Mar., pp. 143–146). This is the first part of a paper in which results obtained by different X-ray techniques are compared and the dependence of the lattice-parameter on the X-ray wavelength is discussed. The author concludes from a survey of 12 German publications between 1923 and 1940, that parameters can be determined reliably to the fourth decimal place from powder specimens, provided the measurement is based on numerous interference lines. As the accuracy was unknown for a measurement based on a single line, he undertook an investigation, together with F. Lihl and F. Regler, using a gold-powder specimen, and measurements were made in a precision-ring camera. The results, confirming the dependence of the measurement on the angle of reflection and on the X-ray wavelength, are reproduced. The author concludes that absolute measurements of the lattice constants must be deduced from large angle deflections with extrapolation to $\theta = 90°$.—J. G. W.

New Techniques in Interference Microscopy. W. Krug and E. Lau. (Die Technik, 1951, vol. 6, Mar., pp. 122–128). Recent developments in interference microscopy are reviewed and attention is drawn to possible applications to the study and measurement of surface finish, and to biology. The following instruments are described : Linnik's original micro-interferometer, the Zeiss interference microscope built in 1943, the instrument built by Précision Mécanique (which employs a single objective lens), and the new microscope developed in the authors' laboratories of the Deutsche Akademie der Wissenschaften, Berlin. Illustrations include photographs of razor edges before and after use, and balls for ball bearings.
J. G. W.

Study of Lower Bainite by the Electron Microscope. P. Coheur and L. Habraken. (Revue Universelle des Mines, 1951, vol. 7, Mar., pp. 107–111). The structure of the needle-shaped bainite crystals is shown to be either of the lamellar or finely divided type. The under-structure obeys the following law of orientation : It is formed on the (111) planes of the austenite lattice.—B. G. B.

What Services Does Microradiography Render to Metallurgy ? G. A. Homès and J. Gouzon. (Mémoires du Centre National de Recherches Métallurgiques, 1950, Dec., pp. 35–44). The uses and the limitations of microradiography are reviewed. Three methods are used in microradiography, namely, polar projection, reflection, and transmission. The last method is described in detail and is considered throughout the paper. The theory of the method is discussed, and its practical applications, with numerous examples and micrographs are given. Microradiography can be used to identify inclusions and to study plastic deformation. A table of absorption coefficients of metallurgical constituents is included.—T. E. D.

The Use of X-Ray Micrography for Studying the Spatial Distribution of Graphite in Cast Iron. M. Nacken and E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 4, Dec., pp. 187–193). A process is described for taking stereo-radiographs of cast-iron specimens, which enable the form and spatial distribution of graphite in cast iron to be studied. The process is illustrated by a series of radiographs of some typical graphite structures.
J. P.

Contribution to the Continued Development of Metallographic Measurement of Grain Size. C. Petersen. (Metall, 1951, vol. 5, Jan., pp. 8–13). The author is in favour of measuring grain size by comparison with idealized, graded pictures. He suggests frequency distributions of triangular shape as a basis for the ideal grain aggregate. The theoretical basis of this approach is briefly discussed, and illustrations of the ideal grain aggregate ' maps,' drawn by the author, are given.

The Structure of Corrosion-Resistant Silicon Cast Iron. A. Wittmoser and E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 83–86). The composition of the corrosion-resistant 13–16% silicon iron corresponds to the α-solid solution of the Fe–C–Si system, yet many physical properties indicate that it cannot be a homogeneous solution. Up till now it has not been possible to examine the alloy metallographically because the corrosion resistance has made etching impossible. It has now been found that alkaline sodium picrate, 80% H_3PO_4 or HF–HNO_3–H_2O mixtures will reveal the macro- and micro-structures of the alloy, especially if used hot. A marked segregation is found in the grains of the solid solution and it appears to be due to decomposition of a silicon-rich silicon carbide.—J. P.

Etching Steels which Contain the Sigma Phase. J. J. Gilman. (Metal Progress, 1951, vol. 59, Mar., p. 377). Etching reveals microstructure by dissolving or by staining differentially. The effects of different etching reagents on the same steel are shown by a series of photographs. These demonstrate the great variety of picture that can be obtained.—E. T. L.

Etching of Metals and Minerals for Ultraviolet Microscopy. E. M. Brumberg, G. A. Zaitsev, and T. G. Porokhova. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 6, pp. 1165–1168). [In Russian].

The Contribution of Electrolytic Polishing to the Chemistry and Physics of Metals. P-A. Jacquet. (Société Française de

Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 1–16). The advantages of the method are given and a large number of scientific applications discussed, including : Electron diffraction and electron microscopy ; the study of plastic deformation, creep, etc. ; the effect of surface on mechanical properties ; and the study of surface electrical properties, corrosion, oxidation, catalysis, and friction.—A. G.

The Influence of Concentration Potential on the Velocity of Sideways Growth of Pearlite Grains. L. N. Aleksandrov and B. Ya. Lyubov. (Doklady Akademii Nauk, U.S.S.R., 1950, vol. 74, No. 6, pp. 1081–1084). [In Russian.] A mathematical expression for calculating the velocity of the sideways growth of pearlite grains was developed. The calculated results were compared with experimental data obtained for two industrial eutectoid steels and one of high quality (carbon 0·98%, silicon 0·002%, manganese 0·04%). Discrepancies between calculated and experimental data for industrial steels are attributed to the presence of impurities not considered in the calculations.—V. G.

The State of Martensite Electrolytically Separated from Quenched Steel. M. P. Arbuzov. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 74, No. 6, pp. 1085–1087). [In Russian]. Martensite isolated electrolytically from quenched steel retains its crystal structure, and X-ray powder photographs give well-defined lines. The diffuse lines obtained from martensite in the steel are attributed to its deformation.

V. G.

Investigations on Temper Martensite. H. Krainer. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 53–61). X-ray diffraction and coercive force measurements have been carried out on hardened and tempered 1·07% carbon steels. Line breadth was evaluated by the Kochendörfer method and particle size, lattice distortion, and tetragonality were determined separately. Internal stress decreases during tempering, rapidly at first and then slowly above 300° C. Martensite tempered at 100–200° C. still shows marked tetragonality, from which it may be concluded that the temper martensite has a carbon content of about 0·33% at a tempering temperature of 100° C., of 0·25% at 150° C., and of 0·15% at 200° C. There is no cubic martensite as assumed by Honda. The high hardness of temper martensite is due to precipitated carbides. The mean size of cementite precipitated at high tempering temperatures was estimated from the coercive force measurements with the aid of the foreign body theory of Kersten and Néel. In the hardened steel the residual austenite acts as the non-magnetic foreign body. The carbon content of the residual austenite is higher than the average in the steel. The intermediate stage structure of a steel containing 0·95% C, 1·0% Mn, and 0·6% Cr was investigated. This was similar to that of temper martensite but differed from it in dispersion of the cementite and lattice distortion. Dislocation density can be estimated from the lattice distortion and particle size.—J. P.

The Effects of Alloying Elements in Steel. J. K. Stone, jun. (American Society for Metals : Industrial Heating, 1951, vol. 18, Jan., pp. 50–56 ; Feb., pp. 248–260 ; Mar., pp. 434–438). The fundamental principles of microstructural change during heat-treatment of steel are discussed. In the first part an introduction is given and an explanation of a typical isothermal transformation diagram. The microstructures of pearlite, bainite, martensite, and tempered martensite are also discussed. In the second part the factors affecting austenite on continuous cooling, and its relation to transformation at constant temperatures are dealt with. In the concluding part, the solution strengthening of ferrite and the stabilization of carbides are considered.—J. A. L.

The Structure of Intermediate Phases in Alloys of Titanium with Iron, Cobalt, and Nickel. P. Duwez and J. L. Taylor. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1173–1176 ; Journal of Metals, 1950, Sept.). The crystal structures of the intermediate phases in the binary systems Ti–Fe, Ti–Co, and Ti–Ni, have been studied by X-ray diffraction methods on alloys prepared by powder metallurgy, and the results are compared with those previously published. The phases Ti_2Fe, Ti_2Co, and Ti_2Ni are shown to have face-centred cubic structures, with 96 atoms per unit cell and closely similar parameters, whilst the phases TiFe, TiCo, and TiNi have body-centred cubic structures with two atoms per unit cell and again closely similar parameters. The iron-rich and cobalt-rich phases have the compositions $TiFe_2$ and $TiCo_2$, and are hexagonal but not isomorphous, whilst the nickel-rich phase has the composition $TiNi_3$, and is also hexagonal. No evidence has been found of a $TiFe_3$ phase or of a cubic modification of the $TiCo_2$ phase.—G. F.

Migration of Carbon in Steel under the Influence of Direct Current. P. Dayal and L. S. Darken. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1156–1158 ; Journal of Metals, 1950, Sept.). The authors describe a method of quantitatively measuring the migration of carbon in austenite, in which a tubular specimen is mounted between electrodes in an atmosphere of nitrogen, and heated by means of direct current. The conditions are such that carbon migrates across the central plane of the specimen only under the influence of the electrical potential gradient, and not under the influence of temperature or concentration gradients. Results obtained by this method are presented.—G. F.

On the Martensitic Transformation at Temperatures Approaching Absolute Zero. S. A. Kulin and M. Cohen. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1139–1143 ; Journal of Metals, 1950, Sept.). The characteristics of the martensite transformation in 18/8 and 1% carbon 20% nickel steels at temperatures approaching absolute zero have been studied in plastic deformation and straight cooling experiments. The transformation proceeds with characteristic rapidity even at temperatures as low as 4° K. The results suggest that in these alloys, the mechanism of martensite formation involves a shear-like displacement of atoms in co-operative movement, rather than a process of atom-by-atom growth, which would proceed at an infinitesimally slow rate at temperatures approaching absolute zero.—G. F.

Transformations and Their Results in 18/8 Steels. J. Dediue. (Métallurgie, 1951, vol. 83, Jan., pp. 23–31). The phenomenon of sensitization and the precipitation of carbides are discussed in relation to the development of the conception of stainless steels. Transformation diagrams in the high-temperature zone and following long periods at low temperatures are discussed. The practical results of transformations on machinability, mechanical properties, resistance to corrosion, and the consequences of the susceptibility to the formation of delta ferrite are discussed.—R. S.

CORROSION

Corrosion Resistance of Wrought Iron and Steel Pipe. S. L. Case. (Metal Progress, 1951, vol. 59, Mar., pp. 378–384). This article considers previous work on the corroding effect of building materials, concrete and steam, and concludes that wrought iron is not better than steel, as regards corrosion resistance, whereas pure iron is worse, and that there is a great difference between the behaviour of different wrought irons.—E. T. L.

Notes on the Electrochemical Behaviour of Paint Film on Steel in Sea-Water. J. T. Crennell. (Journal of the Society of Chemical Industry, 1950, Supplementary Issue No. 1, pp. s36–s38). Painted steel surfaces are normally cathodic to bare steel. This is surprising, and appears to contravene the well-established theory by which corrosion is due to different degrees of aeration. Any screen has this effect, the chemical or physical properties of the paint having no influence. This is in contrast to the preferential corrosion often occurring in crevices, and no explanation is put forward.

N. McE.

The Corrosion of Steel by Sea Salt of Given Moisture Content. S. J. Duly. (Journal of the Society of Chemical Industry, 1950, vol. 69, Oct., pp. 304–306). Experiments are described in which the amount of iron corroded from a steel sheet by sea salt at 24° C. and various relative humidities was measured and compared with the gain in weight of the dried salt when allowed to reach these relative humidities. The amount of corrosion was proportional to the moisture content of the salt complex.—N. McE.

Oxidation of Steels and Alloys. X. Waché. (Métaux et Corrosion, 1950, vol. 25, Nov., pp. 267–276). The oxidation of ferrous, copper, and nickel alloys is studied in relation to the distribution of the elements in the oxide layer and in the original alloy. In ferrous alloys, three layers of oxidation are found : (1) External—10% of total thickness, containing Fe_2O_3 and Fe_3O_4 ; (2) intermediate—50% of total thickness, mainly FeO and Fe_3O_4 ; (3) internal—in contact with the

non-oxidized metal, about 40% of total thickness, essentially FeO. Pfeil's work on the two-way diffusion of oxides across the metal–oxide interface is reviewed. The cases of nickel, manganese, silicon, copper, and cobalt steels are discussed.. R. S.

Heat-Treatment of Steel by Applying Superheated Steam. (Technická Práce, 1950, vol. 6, June, p. 92). [In Czech]. This heat-treatment is intended to produce a corrosion-resistant oxide layer about 0·005 mm. thick. The steel parts are heated for about 30 min. in an electric-resistance furnace at 370° C. in a normal atmosphere. Superheated steam is then passed into the furnace expelling the air, and the temperature is raised to 620° C. and held from 30 min. to 2 hr., depending on the size of the parts. Since the steam is superheated there is no danger of corrosion. The method has proved particularly successful in the case of machine tools; in addition to protecting the tools against corrosion their life is also increased.—E. G.

The Causes of Failure in Multi-Water-Tube Boilers. G. Priseo. (Calore, 1951, vol. 22, Feb., pp. 58–61). [In Italian]. The author describes the failures in the upper banks of multi-water-tube boilers and attributes the causes to corrosion due to poor circulation in the convection banks. A method of overcoming these failures without impairing or interrupting the output of boiler plant is suggested.—M. D. J. B.

On the Rupture of Pieces of Steel. A. Pignot. (Chaleur et Industrie, 1951, vol. 32, May, pp. 126–132; June, pp. 162–172). Failure in metals is attributed to various causes, which are examined. Breaks can originate at inclusions in the metal, and the shape, size, and arrangement of these inclusions determines the quality of the metal. Fractures can then be propagated from one inclusion to another. Corrosion is another important cause of the formation and propagation of fissures, electrolytic as well as chemical attack taking place. The action of the following corrosive agents is examined: Water, carbon dioxide, carbon monoxide, hydrogen, nitrogen, sulphur and its compounds, hydrocyanic acid and allied compounds, and various organic materials including oils and gums. The reasons for the propagation of fissures are elaborated. For detecting faults, the use of radiographic, ultrasonic, and magnetic methods is advocated in preference to mechanical methods, which tend to enlarge the faults and accelerate ageing.—T. E. D.

Problems of Marine Corrosion and Fouling. M. G. Dechaux. (Peintures, Pigments, Vernis, 1951, vol. 27, May, pp. 282–286). The problems arising from the use of anti-corrosion and anti-fouling paints are put forward, and methods used for their study are reported.—T. E. D.

Damage to Oil-Fired Superheaters and Air Preheaters. H. Liander. (Teknisk Tidskrift, 1949, vol. 79, Sept. 17, pp. 637–639). [In Swedish]. Some cases of damage to heat exchangers are reported from a Swedish steam power plant. Vanadium oxide present in the oil catalyses the formation of sulphur trioxide in the hot gases from the combustion, and is therefore thought to be a contributing factor.—B. S. E.

"AC"—A New Corrosion Test. T. E. Lloyd. (Journal of Metals, 1950, vol. 188, Sept., pp. 1092–1093). A description is given of the 'alternate condensation' (AC) method of testing corrosion resistance, in which a specimen mounted on a turntable is alternately exposed to condensing and drying atmospheres. The test closely approximates the actual conditions caused by weather exposure, and permits the specimen to be exposed to varying temperature and humidity conditions and to controlled quantities of contaminators in the air.—G. F.

Corrosion, Cleaning, Inhibition and Passivation of Metals. J. Frasch. (Métaux–Corrosion–Industries, 1951, vol. 28, Feb., pp. 81–94). A survey of the processes of oxidation, deoxidation, and prevention of oxidation of metals is given. The chemical reactions and the chemicophysical theory accounting for them are outlined.—P. F.

The Influence of Internal Stresses on Corrosion Fatigue. H. Bühler. (Métaux–Corrosion–Industries, 1951, vol. 26, Mar., pp. 142–144). It was found that compressive stresses in the surface of a 0·34% carbon steel, induced by quenching below the A_1 point, were accompanied by an increase of about 20% in the fatigue resistance of cylindrical bars 1 in. in dia. in alternating bending as well as in alternating torsion. The improvement was obtained with dry polished specimens as well as with specimens submersed in running town water. P. F.

ANALYSIS

Qualitative and Semiquantitative Analysis of Various Elements Contained in Steel, by Coloured Spot Tests. P. Reboul. (Chimie et Industrie, 1950, vol. 64, Nov., pp. 574–579). Spot tests, using complex organic reagents, are given for the detection and semi-quantitative determination of the following elements in steels and alloys: Nickel, cobalt, molybdenum, chromium, vanadium, tungsten, manganese, copper, zinc, lead, and tin. The tests are carried out on the surface of the material under examination, attack being brought about by means of a drop of the appropriate acid. All the methods, which are described in detail, are both simple and rapid. Interfering elements are given, and where possible, methods of avoiding interference.—T. E. D.

The Use of Spectrography in Italian Foundries. (Australian Foundry Trade Journal, 1951, Jan., pp. 5–6). The principles of spectroscopy, and the development of spectrographic analysis are briefly described. The expansion of its use in Italy and the introduction of quantometers in 1946 are mentioned.—J. E. W.

Spectrographic Determination of Magnesium in Nodular Iron. F. R. Bryan, G. A. Nahstoll, and H. D. Veldhuis. (Foundry, 1950, vol. 78, June, pp. 102–103, 244–248). *See* Journ. I. and S.I., 1950, vol. 166, Dec., p. 389.

Spectrographic Determination of Molybdenum in Steel. Y. Monteaux Correa de Sa. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 59–60). [In Portuguese]. An 'internal standard' method is described, using an iron spectrum (= 2823·28 Å.) of medium intensity, fairly constant, with which is compared microphotometrically a molybdenum spectrum (= 2816·15 Å.) with intensity dependent on concentration. The good agreement between chemical and spectrographic results was not affected by the presence of copper (0·10 to 0·60%) nor by the presence of other special elements up to a total concentration of 3%.—R. S.

A New Direct Reading Electronic Spectrometer. R. Breckpot. (Memoires du Centre National de Recherches Métallurgiques, 1950, Dec., pp. 11–18). The spectral rays, separated into their monochromatic constituents, are received on an electronic multiplier, instead of a thermo- or photo-elastic cell. The flow of electrons at the terminal anode is about 200,000 times the primary flow. The apparatus is described in detail. The multiplier (I.P. 28) is sensitive down to 2100 Å. The method is applied to the determination of phosphorus and carbon in steel. For phosphorus the wavelengths used were 2136·19–2149·11 Å., and the reproducibility of results was ± 2% of the quantity determined (about 0·06%). The range studied was 0·01–0·3% P. In the case of carbon, the wavelength employed was 2296·86 Å., and the reproducibility was ± 1%. The range studied was 0·025–1% C.—T. E. D.

Mass Spectrography. F. Del Valle Rodriguez, A. Bourgeal Ustariz, and E. Orellana Silva. (Revista de Ciencia Aplicada, 1950, vol. 4, Nov.–Dec., pp. 481–494; Jan.–Feb., pp. 17–27). [In Spanish]. The common characteristics of mass spectrographs are described and an attempt is made to classify these instruments. Simple focus systems and the Aston and Dempster spectrographs are described. The Nier model is briefly described and the velocity filter types of apparatus, including those of Bainbridge, Bleakney, and Smythe are surveyed. The double focus system and the apparatus of Bondy and Popper, Mattauch and Herzog, Bainbridge and Jordan, and of Strauss are described. Finally, the authors examine the instruments used for isotope separation, the application of linear accelerators and spectrometers for negative ions.—R. S.

A Method of Increasing the Precision of Quantitative Spectrographic Analyses. P. Emidio F. Barbosa. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 40–46). [In Portuguese]. The process described for the compensation of errors had recourse to an 'internal average.' Instead of preparing a working curve for the determination of a single element, several curves are drawn for the same range of concentration, using various spectra. The element is thus determined by various spectra, and independent results are obtained. The total energy method is used where a weighed mass of the sample is totally consumed. The spectrum is registered from beginning to end of the exposure and its energy is measured in terms of a standard. Details are given of the apparatus, taking of the sample, excitation, illumination of the spectrograph, calibration of the emulsion, and photo-

graphic conditions. Results are given for manganese and iron, showing increased accuracy by the use of the 'internal average' method.—R. S.

A Study of the Conditions of Accuracy in Quantitative Spectrography. P. Emidio F. Barbosa. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 47–58). [In Portuguese]. Errors of measurement and their propagation in quantitative spectrography, particularly in the measurement of capacity, and in the determination of the energy of the external standard, and of gamma are discussed.—R. A. R.

The Importance of Plate Calibration in Spectrochemical Analysis and Means of Obtaining it. F. Baldi. (Metallurgia Italiana, 1951, vol. 43, Mar.–Apr., pp. 135–142). The standard method of quantitative spectrochemical analysis is described and its field of application examined. The importance of the intensity of the analytical lines, rather than their opacity, is stressed. A critical examination is made of the various methods of plate calibration. A method using only a two-step filter is described in which the transparency of the second step is not less than 40% of the first; this method is of practical application and can be used in routine analysis and also in the determination of small impurities in pure metals.

M. D. J. B.

Automatic Electric Excitation and Exposure Regulator for Spectrographs. J. M. Lopez de Azcona and A. Camuñas Puig. (Revista de Ciencia Aplicada, 1950, vol. 4, Sept.–Oct., pp. 394–402). [In Spanish]. The authors describe their automatic spectrograph and the method of obtaining spectrograms. Examples of its application in research and industry are given. The characteristics of other automatic spectrographs are compared with those of the authors' apparatus.—R. S.

The Calibration of Step Filters in the Ultraviolet. F. Baldi. (Metallurgia Italiana, 1951, vol. 43, Mar.–Apr., pp. 129–134). Results are given of tests carried out to determine the transparency in the ultraviolet of the three steps of a filter. The method adopted consists in analysing a number of spectra obtained with different apertures in the intermediate diaphragm of a Zeiss "QU 24" spectrograph illuminated with a mercury vapour lamp. The results obtained by photometer readings are discussed.—M. D. J. B.

Electrolytic Process (Mercury Cathode) for the Determination of Aluminium in Steel. V. F. Alves and C. de Revoredo Barros. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 89–91). [In Portuguese]. Sodium bicarbonate is used to precipitate aluminium, chromium, copper, titanium, vanadium, iron, phosphorus, and a part of the manganese. The precipitate is dissolved in sulphuric acid and aluminium is then isolated electrolytically. Iron, chromium, copper, nickel, cobalt, cadmium, and molybdenum are deposited. In solution with aluminium are vanadium, titanium, phosphorus, and alkalis. A little manganese is in solution but most is deposited. A current of 0·15 amp./sq. cm. was used. Carbon steel samples were dissolved in sulphuric acid (10 cu. cm./g.) and Al_2O_3 was separated, taking with it a considerable part of the iron. Complete separation is carried out by electrolysis. Results are given and details of the method are described. The aluminium content of the steel is calculated by subtracting that in the form Al_2O_3 from the total content of aluminium.

New Process for the Determination of Manganese in Ores and Alloys. M. Yelda E. Ramos and Arykoerner Guerreiro. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 61–64). [In Portuguese]. The new process is based on the reactions of reduction and oxidation of the oxides of manganese by H_2O_2 in an acid and a basic medium respectively. The valency of the manganese is raised and then reduced by sodium oxalate in an acid medium. The excess oxalate is removed by $KMnO_4$ and the amount of $KMnO_4$ used for the total oxalate less the amount consumed for the excess oxalate represents the $KMnO_4$ relative to the manganese of the sample.—R. S.

Comparative Study of the Results Obtained by the Vacuum-Fusion Method and the Gotta Method. J. Varetto and L. Lacomble. (Revue Universelle des Mines, 1951, vol. 7, Feb., pp. 70–73). Either of the above methods for determining oxygen in steel is suitable for examination of the influence of the sampling technique on the oxygen content; however, attention has been directed to certain difficulties which arise. Errors due to superficial oxidation in the Gotta method (deoxidation with aluminium) and gaseous adsorption in the fusion method have been investigated and correction factors successfully applied. The authors claim that the two methods are able to give concordant results with a root mean square error of less than 20%.—B. G. B.

The Tin-Fusion Method for the Determination of Hydrogen in Steel. D. J. Carney, J. Chipman, and N. J. Grant. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 397–403; Journal of Metals, 1950, Feb.). The authors describe an improved method for the determination of hydrogen in steel. Based on the vacuum-fusion method, a tin–iron bath permits melting and operation at 1150° C., heating and stirring being accomplished by induction heating in a water-jacketed silica tube. To prevent hydrogen adsorption, all grease is eliminated from the system by the use of mercury valves. Routine analyses can be made in 15 min., and the accuracy obtained is ± 0·1 p.p.m. on a 2-g. sample.—G. F.

The Sampling and Analysis of Liquid Steel for Hydrogen. D. J. Carney, J. Chipman, and N. J. Grant. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 404–413; Journal of Metals, 1950, Feb.). The authors describe a technique of sampling liquid steel for hydrogen determination, in which a sample is drawn into a thick-walled copper mould and then quenched in dry ice and acetone. The total sampling and quenching time is about 15 sec., and the samples are stored for periods of up to 12 hr. in dry ice. The accuracy has been determined by sampling metal of known hydrogen content in equilibrium with controlled hydrogen–helium atmospheres, 80–100% of the dissolved hydrogen being retained in low-alloy steels, depending on the hydrogen content. The method appears to be applicable to process control of commercial steel melts.

G. F.

New Method for the Rapid Colorimetric Determination of Copper in Iron and Steel. I. Sajó. (Bányászati és Kohászati Lapok, 1950, vol. 5, Dec., p. 707). [In Hungarian]. A rapid colorimetric method for determining copper in the 0·1–0·5% range is described; it takes about 25 min. The accuracy is 1–2% if a mercury vapour lamp is used and 1–5% if colour filters are used.—E. G.

Determination of Tin in Ferro-Tungsten and Tungsten Metal. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 51–56). In this paper by the Methods of Analysis Committee of the British Iron and Steel Research Association two methods are described for the determination of tin in ferro-tungsten and tungsten metal powder. In both, the preliminary decomposition is carried out by attack with mixed acids, including hydrofluoric acid. In the first method tungstic acid is complexed with citric acid before precipitation of the tin as sulphide, a separation procedure previously employed for alloy steels, while the second method utilizes a hydrolytic precipitation and separation of the tungsten; absorption losses of tin in the precipitate are discussed and shown to be of minor importance. In each case the procedure is completed in accordance with the British Standard method for tin in steels. Various alternative methods of decomposition have been examined and data and results showing the comparative performance of the two methods are given.

The Analysis of Tantalum and Niobium in Ferro-Tantalum and Ferro-Niobium. B-E. Jaboulay. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 50–52). The author's previous method was based on the different properties of tantalic and perniobic acids in a sulphuric-acid/hydrogen-peroxide solution. New work shows that a mixture of hydrochloric acid and hydrogen peroxide reduces the contamination of niobium by tantalum, and aids the final precipitation of niobic acid.—A. G.

Determination of the Iron Content of Chromium Plating Baths by the Centrifuge Method. M. Tagliabue and B. D'Alessandro. (Galvano Tecnica: Electroplating, 1951, vol. 4, Feb., pp. 49–50). An aliquot portion of a diluted chromium plating bath is treated with NaOH and Na_2O_2 and evaporated to small bulk. The whole is washed into a centrifuge tube. A solution containing a known amount of iron is treated in the same way. After centrifuging, the heights of the sediments are compared and the iron content of the sample estimated.

J. P.

Determination of Sulphur in Iron, Cast-Iron and Steels by Gaseous Evolution. B. E. Jaboulay. (Chimie Analytique, 1951, vol. 33, Feb., pp. 48–50). The influence of heat-treatment on the amount of H_2S liberated by conc. HCl from iron and steel is discussed. Crude steel, rapidly cooled or tempered at 1200–1300° C. without reheating yields one third of its

sulphur on treatment with conc. HCl($Fe_2S_3 + 2HCl = FeCl + H_2S + FeS_2$). Steel forged or tempered at 1100° and reheated to 800–850° C. yields two-thirds of its sulphur: ($3FeS + Fe_2S_3 + 8HCl = 4FeCl_2 + 4H_2S + FeS_2$). This is due to a change in state of the sulphur: (at 1200° C. or above) $2Fe_2S_3 + FeW$ (or Mo) $\rightleftharpoons$ (around 1100° C.) $3FeS + Fe_2S_3 + W$ (or Mo). The analytical method described employs conc. HCl to liberate the sulphur and zinc acetate solution to absorb the H_2S evolved. Iodine solution is then added and the excess is back-titrated with sodium thiosulphate.

J. E. D.

Variations of Oxidation-Reduction Potential during the Precipitation of Ferrous and Ferric Hydroxides. Marguerite Quintin. (Comptes Rendus, 1951, vol. 232, Mar. 28, pp. 1303–1305). The slopes of curves of potential against *p*H are not in agreement with a precipitation of $Fe(OH)_3$ and $Fe(OH)_2$. There is first formed a charged ferric precipitate, followed by auto-oxidation of nascent ferrous hydroxide, and final establishment of equilibrium between the ferrous and ferric precipitates.—A. G.

Rapid Polarographic Analysis of Liquids and Phosphatizing Baths. D. Bigalli and G. Cinquina. (Anais da Associação Química do Brasil, 1950, vol. 9, pp. 28–33). [In Portuguese]. Ordinary analytical methods are too slow for phosphate baths and often necessitate immobilizing the bath for 24 to 48 hr. A polarographic method is described for the determination of P_2O_5, NO_3, zinc, and manganese.—R. S.

Determination of Impurities in Electroplating Solutions. XX. Traces of Chromium in Zinc Plating Baths. E. J. Serfass and Mary H. Perry. (Plating, 1950, vol. 37, Oct., pp. 1057–1059). A method is described for the determination of very small amounts of chromate ion in cyanide zinc plating baths which may also contain copper, cobalt, nickel, ferric ion, and lead as impurities.—J. P.

Photocolorimetric Method for the Analysis of Nickel in Nickel Plating Baths. G. C. H. Stone. (Metal Finishing, 1951, vol. 49, Feb., pp. 44–48). The nickel ion content of nickel-plating baths may be estimated by determining the transmittancy of the diluted solution at 640–650 mμ. The colour density is essentially independent of the concentration of sulphate, chloride, sodium, and ammonium ions. Variations in boric acid content and *p*H have a minor effect (not exceeding 3%).—J. P.

The Present State of Microanalysis. C. Duval. (Report on 1st International Congress on Microchemistry: Chimie et Industrie, 1951, vol. 65, May, pp. 646–656). The subjects discussed were the teaching of microanalysis, materials and apparatus used, physical methods employed, inorganic and organic microanalysis, and the applications of microanalysis.

T. E. D.

Determination of Chromium in Metals and Ferrous Products. L. Roger. (Fonderie, 1951, Feb., pp. 2359–2362). The value of certain methods of analysis for chromium is often disputed, especially the perchloric method. Some affirm that, during the attack on the metal, chromium is lost as volatile chromyl chloride. Others assert that the oxygenated compounds formed during the boiling of the acid influence the results. The author's experiments show, however, that these fears are ill-founded and that it would be a pity to reject this rapid method which is very reproducible.—R. S.

Application of Atomic Structure Investigations in Welding Research. H. Krainer. (Berg- und Hüttenmännische Monatshefte, 1950, vol. 95, Dec., pp. 282–284). The advantages of using X-ray diffraction for the determination of constituents of weld metal are pointed out.—U. E.

Spectrography as a Method of Non-Destructive Testing of Metals. L. Lœuille. (Métaux–Corrosion–Industries, 1951, vol. 28, Feb., pp. 95–96). Some work at the Satory spectral-analysis laboratories on armour plating is used to illustrate the versatility of this method in non-destructive testing. The analysis is rapid, quantitative, and requires no more than about a milligram of the material. The high sensitivity of the analysis facilitates identification of impurities and inclusions of microscopical dimensions if they are present in the surface of the metal. All metals and alloys are suitable for spectrographic analysis.—P. F.

A New Method of Analysis by Sparks. Shiguéo Okétani. (Métaux et Industries, 1950, No. 6, pp. 131–143). Sorting steels by grinding sparks is too coarse to permit separation of alloy steels of closely related composition and is inapplicable to some steels, *i.e.*, copper-bearing types. These limitations are largely removed in the author's method which was developed in Japan. Grinding dust from the sample is passed through three sieves of decreasing mesh. The residue of medium size is dropped into a small electric furnace and the ignition temperature is recorded. The coarsest powder is placed into a furnace maintained at 1000° C. and the shape and colour of the sparks as well as the noise of the explosions are noted. The fine fraction is used to determine the ignition temperature and the shape of the sparks in the case of alloy steels which would not easily ignite in the electric furnace. Details of the ignition temperatures and photographs and drawings of sparks of a number of carbon and alloy steels are given. A correlation between the dimensions of the grinding pellets and the carbon content of the steel shows a linear decrease in size with increasing carbon content. Much information is obtainable by observing the pellets under a low-power microscope. A complementary method by which grinding dust is dropped through a horizontal Bunsen flame and the colour and noise of the burning metal are observed and the fused residues are examined microscopically, facilitates the analysis of a great variety of alloy steels which would be most difficult to identify by the ordinary spark method.—P. F.

The Direct Reading Analysis of Low-Alloy, Tool, and Stainless Steels with Quantometer. M. F. Hasler. (Transactions of the Instruments and Measurements Conference, Stockholm, 1949, pp. 8–15). The sphere of activity of spectrographic analysis is defined and limited by the inherent properties of the photographic emulsion. A new instrument is described in which this limitation does not arise. In the production control quantometer of the Applied Research Laboratories of Glendale, California, an electron multiplier is used instead of the photographic emulsion as the light-measuring device. An error in the analysis of only 0·1% of the quantity measured is obtainable by this means, *i.e.*, about one-tenth of the error commonly obtained with standard equipment. A complete duplicate analysis of a stainless steel, including cut-off and grinding of a sample, is obtainable in a little over 3 min. A comparison of the performance of the equipment making repeated analyses from several samples is given. The chemical analysis is also given and serves as standard. Details of the equipment and the ranges of concentrations of various alloying elements together with the corresponding standard deviations and the coefficients of variation are tabulated.—P. F.

Centre for Polarographic Study. G. Semerano. (Ricerca Scientifica, 1950, vol. 20, June, pp. 786–795). [In Italian]. Details of the activities of the Centro di Studio per la Polarografia during the years 1948 and 1949 are given. This review of research covers work carried out by many authors on 14 specific subjects intimately connected with polarographic study. A very comprehensive bibliography is given.

M. D. J. B.

ECONOMICS AND STATISTICS

Iron and Steel Industry in Chile. E. Garrido Merino. (Acero y Energia, 1951, vol. 8, Jan.–Feb., pp. 13–14). [In Spanish]. The economic developments which culminated recently in the completion of the blast-furnace plant at Huachipato with a capacity of 250,000 tons of pig iron per annum are described.

R. A. R.

How the Defence Production Will Influence Materials Supply. L. M. Jaroff. (Metallurgia Italiana, 1951, vol. 43, Jan., pp. 1–5). The author reviews the raw-materials position of the U.S.A. and attempts to forecast the measures which may have to be taken if production goes over entirely to armaments. Stocks and the means of replenishing them are considered. Especial attention is given to steel, aluminium, magnesium, copper, nickel, chromium, manganese, zinc, and lead. Other strategic metals considered are tin, tungsten, and niobium.—M. D. J. B.

MISCELLANEOUS

New Laboratories for United Steel Companies' Research and Development Department. (Metallurgia, 1951, vol. 43, Feb., pp. 83–84). **New Metallurgical Research Centre: The Swinden Laboratories of the United Steel Companies Ltd.** (Iron and Coal Trades Review, 1951, vol. 162, Feb. 9, pp. 325–326). A short description is given of the organization of the new Swinden Laboratories of The United Steel Companies, Ltd., which are now being constructed, and brief details of the research work proposed and in progress are included.

BOOK NOTICES

Festival Week of the Hungarian Academy of Science. (Bányászati és Kohászati Lapok, 1950, vol. 5, Dec., pp. 684–688). [In Hungarian]. The papers presented at this festival included the following on metallurgical subjects:

Possibilities of Utilizing Home Produced Ores, by M. Szele.

Steel Manufacture with Compressed Air, by K. Kerpely.

Hydrogen and Nitrogen Contamination of Steel Produced with Compressed Air, by J. Verö.

Mathematical Solution of the Theoretical and Practical Problems of Rolling Operations, by S. Geleji.

Miscellaneous Costs in Industry. G. Ceradelli. (Rivista di Meccanica, 1951, vol. 2, Feb. 10, pp. 5–9). [In Italian]. This article deals with those items which usually evade the normal costing systems in industry. The author shows how by statistical analysis and careful control it is possible to keep a check on steam, water, air, gas, and electric consumption.—M. D. J. B.

Demineralization and Purification of Industrial Waters. A. C. Nigro. (Ingenieria e Industria, 1950, vol. 17, Mar.–April, pp. 88–95). [In Spanish]. The nature of impurities in water and the phenomenon of hardness are considered. A table gives the types of impurities, their physical state, effects, and limits of tolerance. Special requisites for boiler feed waters are discussed and methods of eliminating each impurity, together with the results of each treatment are listed. Methods, results, and costs of ionic exchange demineralization processes are surveyed.—R. S.

Review of Tracer Techniques in Metallurgy. G. H. Guest. (Metal Progress, 1951, vol. 59, Mar., pp. 366–370). This review considers the application of radioactive tracers to problems connected with ore dressing, smelting and refining, the utilization of materials, and physical metallurgy. Examples are the study of firebrick erosion, corrosion and wear resistance, and the investigation of self-diffusion.

E. T. L.

Radioactive Isotopes: Application in Industry. S. Hähnel. (Teknisk Tidskrift, 1950, vol. 80, Sept. 9, pp. 765–773). [In Swedish]. The applications of radioactive isotopes in metallurgy, and mechanical and chemical technology are outlined. Radiation monitors are discussed and safety measures emphasized.—B. S. E.

Variables Encountered in Tracer Experiments in Metallurgy. C. D. Starr, J. R. Lewis, and T. J. Parmley. (Metal Progress, 1951, vol. 59, May, pp. 673–680). The authors discuss the effect of the following variables on the accuracy of experiments using tracers: The background radiation, the activity of the sample, the form and weight of the sample, the layout of the apparatus, and the specimen's absorption. Methods of minimizing these are tabulated.—E. T. L.

Factors Affecting Production in the Engineering Industry. E. W. Steele and W. Symes. (Metropolitan-Vickers Gazette, 1951, vol. 23, Apr., pp. 343–349). The planning of efficient production should follow the course: Inception of the idea behind the product; the testing of the model for function; pilot production and setting the standards of quality; planning of flow production; the vetting of production layout by time and motion study; and the regulation of inventory, stocks, and work in progress.—T. E. D.

Construction and Operation of Tonnage Oxygen Plants. M. J. Conway. (Engineers' Club of Virginia: Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 58–65). After a brief review of early methods of oxygen production, the author describes modern methods of cheap oxygen production with particular reference to a plant at Winnie, Texas, which produces 90–95% pure oxygen at a rate of 175 tons/day. A feature of the plant is that it operates on an entirely self-contained cycle. Except for cooling water and a source of power nothing is required for the operation other than the air that is processed. Technical details of the process are given and the design problems and mechanical features discussed including air compression, air cleaning and cooling, reversing valves, reversing exchangers, fractioning equipment, heat exchangers, refrigeration by expansion, piping, insulation, controls, and instrumentation.

M. D. J. B.

Critical Comparison between the Italian, French and American Classifications of Metallurgical Literature. M. Scortecci. (Metallurgia Italiana, 1951, vol. 43, Mar.–Apr., pp. 110–120). There are today three major systems of classifying metallurgical literature. These are examined in detail and their relative merits discussed. The well-known Universal Decimal Classification is briefly referred to and it is shown how this may become cumbersome where specific metallurgical subjects are concerned. The French, Italian, and American methods, using a combination of letters and numerals, are described and the methods of grouping the subject headings are given.—M. D. J. B.

BOOK NOTICES

CHESTER, D. N. "*The Nationalised Industries.*" 8vo, pp. 87. London, 1951: George Allen and Unwin, Ltd. (Price 7*s.* 6*d.*)

This book, published for the Institute of Public Administration, attempts to analyse the statutory provisions governing the following public corporations, the B.B.C., the Bank of England, the National Coal Board, the Colonial Development Corporation, the two Airways Corporations, the British Electricity Authority and the North of Scotland Hydro-Electric Board, the Gas Council, the Iron and Steel Corporation, the Overseas Food Corporation, the Raw Cotton Commission, and the Transport Commission. The 'pre-1939' Corporations, of which the Port of London Authority is the sole survivor, are also considered.

The most important of these to the ferrous metal industry is the Iron and Steel Corporation; the author points out the great structural difference between this and the Coal Board; a great degree of decentralized management is preserved under the former which is not provided in the latter, and this extends to the requirement that each of the now publicly owned companies must produce its own profit-and-loss account and balance sheet. This book provides, in fact, a useful comparison between the structure of the iron and steel industry under national ownership, and that of the other corporations, but as far as a close study of the legal aspects of the Iron and Steel Act is concerned, it is not as useful as, say, "The Iron and Steel Act, 1949," by W. Gumbel and K. Pollen (*see* Journ. I. and S.I., 1951, vol. 167, Apr., p. 471).—J. P. S.

DAWKINS, J. M. "*Zinc and Spelter.* 12mo, pp. 35. Oxford, 1950: Zinc Development Association.

Of the more common metals, zinc had to wait the longest time before being either recognized as an element or commercially extracted. Brass had been made for centuries, by the heating of zinc ores with charcoal and copper, before the metal itself was isolated. Even when finally produced in quantity, a true metallic nature was denied it: Paracelsus called it a "bastard of copper," and even in the 19th century some Birmingham brassfounders stuck to the use of calamine and charcoal, believing that the use of metallic zinc produced an inferior brass. Similar ignorance and confusion surrounds the very name of the metal. The origin of its modern cognomen is far from clear, and that of the word 'spelter' may spring from several roots, possibly, according to the author, from 'pewter'; the Dutch, among the first importers of metallic zinc from the Far East in the 16th and 17th centuries, found, apparently, no other word to describe it.

This book is a very useful and concise contribution to the history both of the extraction and of the nomenclature of zinc. The author has used many sources and much

Corrigenda

In the April *Journal*, p. 468, column 1, abstract 2, the author's name should be W. Samans, and on p. 470, column 2, last abstract, the author's name, S. Ein, was omitted. On pp. 465 and 466 there appeared several abstracts relating to the 12th Congress of the Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques. This Congress took place in 1949, not 1950.

In the abstract on the equipment in the hot strip mill of John Summers and Sons, Ltd., in the June *Journal*, p. 195, it was erroneously stated that four finishing stands were driven by 300-h.p. motors; this should have read "3000-h.p. motors."

erudition, and made a most interesting picture of the progress of the metal from its obscurest days when the ore, known significantly as 'contrefey,' was used to impart a false golden appearance to copper, to the present, when the metal is the second most widely used non-ferrous metal.

"*Gmelins Handbuch der anorganischen Chemie.*" Achte Auflage. System-Nummer 6. "*Platin*" Teil A, Lieferung 6, "*Die Legierungen der Platinmetalle: Osmium, Iridium, Platin.*" 8vo, pp. xxii + 719–854. 1951: Verlag Chemie G.m.b.H., Weinheim/Bergstrasse. (Price DM 36.–)

The thoroughness with which the literature is examined in order to record and classify all references to a particular metal and its alloys is once again exemplified in the present work which is the sixth and last handbook of the series on the platinum metals. It covers the alloys of osmium, iridium, and platinum.

The platinum–iron alloys are dealt with in eight pages which include a constitutional diagram based on thermal analyses by E. Isaac and G. Tamman and magnetic measurements by L. Graf and A. Kussmann. Curves show the linear thermal expansion between − 180° and + 700° C. for 12 of these alloys in the composition range 54 to 100% platinum. The magnetic properties, extracted from many sources, are comprehensively dealt with.

The list of contents at the front of this handbook covers all of the six works in the platinum series.—R. A. R.

HUNT, F. W. "*Your Factory and the Law.*" 8vo, pp. ix + 156. London, 1951: Seven Oaks Press, Ltd., (165 Victoria St.). (Price 15*s.*)

As the author, himself a Factory Inspector for forty years, points out, a factory may be anything from an establishment employing thousands of workers, to the tiny workshop of a dressmaker with one apprentice. The 1937 Factories Act has, to avoid legal confusion, listed a number of other types of establishment which must be considered as factories for the purposes of the Act; these include shipyards and shipbreaking yards, railway locomotive building and repair shops, printing shops, hotel and hospital laundries, and so on. Moreover, while mines and quarries do not come under the Acts, the further treatment of their products at some other premises, as for example, in the manufacture of road materials, brings those other premises within the scope of the Acts. Even in agricultural work, the farmer who grinds his neighbours' corn, for profit and employing labour for the purpose, places that part of his premises within the scope of the Acts.

It is therefore necessary for practically every industrial employer to be familiar with the Factory Acts. This book will be an immense help to him; the statutory requirements concerning factory structure, amenities such as washing and sanitary arrangements, temperature and ventilation, safety precautions, hours of employment, piece-work payment, and so on, are clearly stated in lucid terms, and marginal references are given to the appropriate sections of the Acts. In conclusion, while the author describes the legal powers of Inspectors under the Acts, he is at pains to explain that they are better pleased if observance is brought about by help, advice, and co-operation than by the force of legal remedy.—J. P. S.

LEITNER, F. and E. PLÖCKINGER. "*Die Edelstahlerzeugung—Schmelzen, Giessen, Prüfen.* 8vo, pp. viii + 490. Vienna, 1950. Springer Verlag.

This excellently produced book can be welcomed, for it deals scientifically and technically with a wide field covering the melting, casting, and testing of high-quality carbon and alloy steels. The book is homogeneous and very useful. The thread running through it is perhaps technological, but at no point is the fundamental background very distant. The reviewer finds some difficulty in translating the title—'Noble Steels'—steels which have become ennobled through selection of the process for their manufacture and the control of its operation. 'Alloy Steels or 'Special Steels' might have served, but after reading and re-reading the emphasis in the book is on quality. Had the book been written 50 years ago the word 'body' would have been employed very frequently. But there is a great difference, the present authors express themselves very clearly on the subject of quality and the factors which exert a controlling influence on it.

Austria has a great tradition as a steelmaking country. Iron of superlative quality has been obtained from the Ore Mountain, now mined in terraces from the bottom to the top of its several thousand feet. There are many Austrian names in the story of iron metallurgy, notably in such sections as are today judged of prime importance. Peter Ritter von Tunner gave great impetus to the teaching of scientific metallurgy, and was the creator of the School at Leoben. Although a great teacher he kept closely in contact with practice, superintending the first Bessemer blow in Austria. Jüptner taught and wrote 40 years ago on the application of physical chemistry to metallurgy. His paper at the 1907 Iron and Steel Institute meeting in Austria opened: "There is at the present time an almost daily increase in the cases in which industrial practice is profiting by the application of the laws of modern physical chemistry." Later Ludvik of Vienna was among the first to investigate and theorize on the fascinating subject of the brittle state of steel. The present authors are definitely in the succession, and, according to the preface, set themselves the task of threading together the clearly understood laws of metallurgical reactions and the practice of metallurgy.

In dealing with such a wealth of material they outline the theoretical foundations of the processes and the phenomena of solidification, and the practice of steelmaking and casting. Some seven-ninths of the book are devoted to steelmaking and one-ninth each to casting and testing. The constructional developments of the furnaces are not dealt with, and it is pointed out that the most modern furnace, of itself, is no guarantee that high-quality steel will be produced in it. On the other hand furnace linings are dealt with, for the linings take part in the reactions.

The chemistry and physics of refining are discussed at length, the section on the absorption of oxygen by the bath is interesting and the present and potential use of oxygen gas for this purpose is discussed. The consideration of 'free' ferrous oxide is appropriately placed. Similarity between the reactions of manganese and phosphorus is pointed out; as is the possibility of using nitrogen as an alloying element in high-chromium steel. The authors are convinced of the deleterious effects of hydrogen in steel, and state that there are no known means of making such hydrogen safe. They can only recommend the practical steps of boiling it out, and the employment of dry additions and gas-free ferro-alloys. An interesting section is devoted to the slag-reaction processes, indicating the fundamental importance of a great increase in the contact surface of the reagents so that the adequate speed of the surface reaction is not handicapped by the slower diffusion process through the metal. The fluidity of these special slags for dephosphorizing, desulphurizing, and deoxidizing, which is a prerequisite for their reactivity, enables a complete separation of slag from metal to take place after treatment, mixing, and the removal of the original suspensions in the steel. In practice, although no actual reduction in the inclusion count may occur, the type and distribution of the inclusions may be favourably influenced. In the section dealing with the control of the processes, the immersion pyrometer receives scant attention. Interesting figures are given for the time taken in various chemical determinations and it is noted that chromium may be estimated in low-manganese slags in say nine minutes. The hot-extraction process is considered to be ruled out as a furnace-stage process, but the indirect determination of oxygen by aluminium additions to a test ingot is not. Comparative methods for determining metal and slag viscosities are given. Some of these seem to the reviewer to be capable of development. Similarly technological tests now in use for determining the state of oxidation of the bath are described. Potential methods depending on the time taken for an oxide film to form on the surface of a test ingot, coupled perhaps with some form of radiation analysis, are sketched.

Much space is devoted, as might be expected, to the open-hearth furnace. Acid and basic techniques are described in detail, and data on representative charges given. It is concluded that the maximum contents of alloying elements in high-quality steels which may be produced by this process are: Mn 2·5%, Cr 2·5%, Ni 5·0%, and Mo 0·5%.

The authors consider that the development of electric furnaces from the constructional and electrical points of view is by no means completed. Some of their advantages

emphasized by the authors are no lower limit to size, greater ease of supervision, greater stage of readiness for melting, and economy in discontinuous working. The increasing importance of the graphite-rod furnace is noted. Balanced arguments are presented as between acid and basic processes. Acid processes are favoured by lower melting costs, a better ingot surface with lower ingot machining costs, and an almost complete absence of liability to hair-line cracks. These factors also hold in the steel foundry, but the authors state from time to time, and without reservation, that basic steel is tougher than acid.

The section on vacuum melting and casting is most interesting. The application of the latter is at present considered to be to steel with special physical properties. The possibilities of both gaseous deoxidation, and the removal of carbon down to 0·01% by oxides, facets of the same theme, are discussed. The possibility of employing low superheat and slow casting *in vacuo* to generate a fine equiaxed in place of the strongly columnar type of ingot is pointed out. On the other hand the convenient production of any desired superheat in the graphite rod type of furnace, single it out for the production of very small ingots and castings. These furnaces are very convenient to operate. A detailed consideration of the authors' excellent section on slag-reaction processes and their combination with existing processes and duplexing, from the points of view of product quality and cost would lead too far. The section on the losses of elements in the various processes is the only one of its kind of which the reviewer is aware.

The authors conclude the steelmaking section with a critique on the choice of process. They lay down that the basic open-hearth furnace is the first choice for carbon or lightly alloyed constructional steels, and the acid open-hearth or arc furnace for slightly greater alloy content—if high transverse strength and insensitivity to overheating are demanded, then the basic electric furnace. On the other hand the hardenability of acid steels is greater and the susceptibility to hair-line cracks definitely less. The arguments are continued for more highly alloyed and for tool steels.

The solidification of steel is dealt with admirably and a clear picture is given of the conditions determining the formation of columnar and equiaxed crystals. The effect of the many technical factors encountered on this vital relation is clearly propounded. A balanced position is evolved between bottom and top casting.

The technological methods described in the section on testing will repay careful study.

The reviewer finds a wealth of information in the book, particularly on subjects which are often passed over. The writers make their standpoint very clear indeed. It is regretted that there are practically no references to British work. This book may encourage us to pay even more attention to this field. All in all, the book is excellent and timely: the judgments are balanced. It repays reading by all who are interested in the 'quality' of steel.

G. WESLEY AUSTIN

MITCHELL, J. W. (Editor). "*Fundamental Mechanisms of Photographic Sensitivity.*" 8vo, pp. viii + 345. London, 1951: Butterworth's Scientific Publications. (Price 63*s.*)

This book is a collection of some 40 papers delivered at a conference on the subject of the title, in Bristol in March, 1950. The five sections cover 'The Physical Properties of Silver Halides,' 'Production and Properties of Silver Halide Grains in Photographic Emulsions,' 'Photographic Sensitivity,' 'Latent Image Formation' and 'Nuclear Track Emulsions.' The papers should be of great interest to those working on the practical applications of highly sensitive photographic materials and to those carrying out fundamental photographic research.—J. P. S.

UNITED STEEL COMPANIES, LTD. "*Standard Methods of Analysis.*" 8vo, pp. xv + 169. Illustrated. Sheffield, 1951: United Steel Companies, Ltd. (Price 17*s.* 6*d.*)

The methods of analysis of iron, steel, ferro-alloys, and fluorspar described in this book are selected methods which have been adopted by and are actually in use as standard in the laboratories of The United Steel Companies. The inception of the book, in 1933, was due to Dr. T. Swindon, and this is the fourth edition. The compilation and revisions have been the subject of co-operative effort by chemists from each branch and the Central Research Laboratories of the Company, who made free use of existing publications and data.

The major addition included in this enlarged fourth edition is a new section dealing with polarographic and absorptiometric methods, and with mercury cathode separations.

Part I of the book lists methods for the estimation of 21 elements in iron and steel; Part II deals with physico-chemical methods; Part III gives methods for the analysis of ferro-alloys, and Part IV gives details of the determination of five components of fluorspar. Rapid methods often found useful in the works for control purposes are not included.

This excellent book, which can be recommended to all analytical laboratories, is permeated throughout by the practical experience of the compilers, as witnessed by the numerous notes on each procedure. The only small criticism which can be made is that no indication of the possible accuracy of the methods is given. On page 8 one is told to prepare an $N/100$ iodine solution by dissolving 1·2692 g. of iodine, but it is hard to believe that the accuracy of the relevant determination (arsenic) is one part in 12,500.

The very reasonable price of this book should contribute to its wide appeal.—J. B. BOOKEY

NEW PUBLICATIONS

COTEL, E. "*Die Grundlagen des Walzens.* 2. Aufl. 8vo, pp. 122. Illustrated. Halle (Saale) 1950: Verlag Wilhelm Knapp. (Price DM 7.40).

DUCROCQ, A. "*Destins Industriels du Monde.* 8vo, pp. xii + 326. Paris, 1951: Editions Berger-Levrault.

HOT DIP GALVANIZERS' ASSOCIATION. "*International Conference on Hot Dip Galvanizing Held at Copenhagen* 17–21 *July* 1950. La. 8vo, pp. 161. Illustrated. Oxford, 1951: The Association. (Price 30*s.*)

HUNT, FRANCIS W. "*Your Factory and the Law.* 8vo, pp. ix + 156. London, 1951: Seven Oaks Press, Ltd. (Price 15*s.*)

JUNGBLUTH, H. "*Giessereitechnik.* I: *Eisengiesserei.*" (Sammlung Göschen Band 1159). Sm. 8vo, pp. 126. Illustrated. Berlin, 1951: Walter de Gruyter and Co. (Price DM 2.40)

KLUSS, E. "*Einführung in die Probleme des elektrischen Lichtbogen- und Widerstandsofens.* 8vo, pp. 2635. Illustrated. Berlin, Göttingen, Heidelberg, 1951: Springer Verlag. (Price DM 28.50)

MOHLER, J. B. and H. J. SEDUSKY. "*Electroplating for the Metallurgist, Engineer and Chemist.* 8vo, pp. 257. New York, 1951: Chemical Publishing Co., Inc. (Price $5)

MOND NICKEL COMPANY: "*Isothermal Transformation Diagrams for Nickel Steels.* La. 8vo, p. 57. Illustrated. London: The Company.

PHYSICAL SOCIETY. "*Reports on Progress in Physics.*" Vol. XIV (1915). Executive Editor, A. C. Stickland. La. 8vo, pp. iv + 412. Illustrated. London, 1951: The Physical Society. (Price £2 10*s.*)

"*Quin's Metal Handbook.* 1950. Thirty-Seventh Year of Publication. Obl. 32mo, pp. 612. London: Metal Information Bureau, Ltd. (Price 20*s.*)

ROGERS, B. A. "*The Nature of Metals.* 8vo, pp. vi + 248. Illustrated. Cleveland, Ohio, 1951: American Society for Metals; Ames, Iowa: The Iowa State College Press. (Price $3)

SPOTTS, M. F. "*Design of Machine Elements.*" 8vo, pp. x + 402. Illustrated. London, 1951: George Allen and Unwin, Ltd. (Price 25*s.*)

WEILL, G. F. "*Industrial Polishing of Metals.*" Pp. 194. London, 1951: Iliffe and Sons, Ltd. (Price 21*s.*)

XUM

RICHARD ELSDON

RICHARD ELSDON was born in London in 1887 and was educated at the St. Stephens Higher Grade School and at the Technical Institute, Westminster.

He joined the staff of The Iron and Steel Institute in 1904 under the secretaryship of Bennett H. Brough. He was promoted to Library Assistant in 1907 and was appointed Librarian in 1908. Throughout his long association with the Library he has devoted his energies to building up this Department to be of the greatest service to the Members and to the industry, and to the maintenance of a close co-operation with other British and foreign technical libraries. Under his charge the collection of volumes has increased from about 2000 to the present total of 30,000, and the number of books borrowed from 100 to 12,000 per annum. He has introduced several developments, including the loan of volumes to Members, which was sanctioned by the Council in 1914, and the compilation of bibliographies, some of which form the Bibliographical Series published by the Institute. He also began and developed the Information Department. In addition to his many duties as Librarian, Mr. Elsdon for many years served as an abstractor for the Journal and compiled the Indexes. He has also rendered service in the arrangements for the Autumn Meetings, Banquets and other social functions held by the Institute and has visited many iron and steel plants both in this country and abroad.

During the First World War Mr. Elsdon served in the Essex Regiment and the Royal Inniskilling Fusiliers and was severely wounded at Langemarck during the Third Battle of Ypres in 1917. During the last war he served in the Home Guard.

In 1937 when the Libraries of the Institute of Metals and the Iron and Steel Institute were amalgamated he was appointed Librarian of the Joint Library.

At the end of this year Mr. Elsdon retires after more than 45 years' work on behalf of the Members of the Institute. The present scope and activities of the Library are a tribute to his efforts.

Richard Elsdon
Librarian 1908—1951

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

ANNUAL GENERAL MEETING, 1951

THE EIGHTY-SECOND ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on 30th and 31st May and 1st June, 1951, at the Offices of the Institute. Mr. J. R. MENZIES-WILSON, O.B.E., the Retiring President, was in the Chair at the beginning of the Meeting, his place thereafter being taken by Mr. RICHARD MATHER, the new President.

Sessions were held at 10 A.M. and 2.30 P.M. on Wednesday and Thursday, on which days a buffet luncheon was provided in the Library of the Institute, and at 10 A.M. on the Friday. On the Wednesday evening a Members' Dinner was held at the Dorchester Hotel, Park Lane.

The minutes of the previous meeting were taken as read and signed.

The **President** (Mr. J. R. Menzies-Wilson) welcomed the members and guests who included Dr. Oberegger, President of the Austrian Iron and Steel Institute and Chairman of the Reception Committee for the meeting in September, Lt.-Col. Nigel Watson, O.B.E., Joint Honorary Secretary for the Austrian meeting, and Dr. B. Matuschka, the author of a paper; and from America Dr. J. B. Austin and Mr. Owen R. Rice, who had come specially to read papers.

He referred to the deaths of two Hon. Vice-Presidents, Lt.-Col. Sir John Greenly, K.C.M.G., on 31st December, 1950, and Professor Thomas Turner on 31st January, 1951. Professor Turner was the oldest member of the Institute, having been elected in 1887.

PRESENTATION OF REPORT OF COUNCIL AND STATEMENT OF ACCOUNTS FOR 1950

The **President** then presented the Report of Council and Statement of Accounts for 1950, already published in the May issue of the *Journal*. In the unavoidable absence of the Hon. Treasurer, Mr. James Mitchell, he referred to the accounts as follows:

"The Balance Sheet and Income and Expenditure Account are drawn up in the usual form. Income, at £58,500, was £3250 higher than in the previous year, while expenditure, at £52,600, was £800 less, resulting in a surplus of £5898, which was £4050 greater. This satisfactory result is largely due to the income from subscriptions, which again increased (£16,300, as against £15,900), and to the substantial sum which it has been possible to transfer to the General Account from the Publications Account. Details of the latter are shown separately. We have thought it right to transfer the whole of the surplus to General Reserve.

Costs, in the case of the Institute, as everywhere else in the country, are continuing to increase. The cost of paper is a very big item, and is now substantially higher; indeed, it is likely that by the end of this year paper required for the *Journal* will cost us three times as much as at the end of last year. There are other increases in expenditure which we cannot avoid; for example, we have been informed that the Institute is no longer exempt from payment of rates.

We are taking such steps as are open to us to increase our revenue. Although the surplus this year is likely to be smaller, the financial position is sound, and it is the endeavour of your Council to see that it remains so."

Mr. **Richard Mather** seconded the motion, which was carried unanimously.

AWARD OF THE BESSEMER GOLD MEDAL FOR 1951 TO MR. BENJAMIN FAIRLESS

The **President** announced that the Bessemer Medal for 1951 had been awarded to Mr. Benjamin Fairless, President of the United States Steel Corporation, in recognition of his distinguished service to the iron and steel industry. Mr. Fairless was unfortunately unable to be present, but Sir Charles Goodeve, who was in America, leading a production team, had kindly consented to make the presentation during the General Meeting of the American Iron and Steel Institute in New York on 24th May. It had been reported by Mr. Ian Elliott, who was present, that it was a very popular and pleasant function. (A condensed report of the speeches is given on p. 100.)

PRESENTATIONS

The **President** then made the following presentations:

The Sir Robert Hadfield Medal for 1951 to Mr. W. Barr, of Colvilles, Ltd., in recognition of his contributions to research in steelmaking.

The Carnegie Silver Medal for 1950 to Mr. A. B. Winterbottom, of the Technical University of Norway, Trondheim, for his paper on "Optical Studies of the Oxidation of Iron at Temperatures in the Range 20–265° C.," published in the *Journal* for May, 1950.

The Ablett Prize for 1950 jointly to Mr. D. A. Wise

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and Dr. L. N. Bramley, both of B.I.S.R.A., for their paper on "Proposed Method of Specifying Travel-Motion Performance for Steelworks Overhead Cranes." The President referred also to the unfortunate absence of Capt. Ablett, who was ill.

The Williams Prize for 1950 to Mr. T. H. Harris (Brymbo Steelworks, Ltd.) and Mr. W. H. Everard (Edgar Allen and Co., Ltd.) for their paper, written jointly with Mr. D. J. O. Brandt, on "The Use of the Oxygen Lance in British Electric Furnace Practice."

In making the presentation the President remarked: "The Williams Prize may be awarded only to someone who is regularly employed in a British iron and steel works, in a position not superior to that of manager of any one technical department. As a result, the staff of B.I.S.R.A. are not eligible. The Council thought that this was unfair to Mr. D. J. O. Brandt, especially as they knew of the important part which he had taken in initiating and conducting the experiments. Accordingly they have decided to award a special prize of equal value to Mr. Brandt."

ANNOUNCEMENTS

The **Secretary** (Mr. K. Headlam-Morley) made the following announcements:

Changes on the Council since the last General Meeting, in November, 1950:

Honorary Members of Council during their periods of office:

Professor A. J. Murphy, M.Sc., President of the Institute of Metals, in place of Mr. H. S. Tasker.

Mr. A. B. Ashton, M.Sc., President of the Manchester Metallurgical Society, in place of Mr. E. J. Heeley.

Mr. E. T. Gill, President of the Sheffield Metallurgical Association, in place of Dr. J. White.

Retiring Members of Council—In accordance with Bye-Law 10 the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1950, as being due to retire at the present Annual Meeting:

Vice-Presidents—Mr. G. Steel, the Hon. R. G. Lyttelton, and Captain H. Leighton Davies, C.B.E.

Members of Council—Mr. C. R. Wheeler, C.B.E., Mr. D. A. Oliver, Dr. C. Sykes, F.R.S., Mr. W. Barr, and Sir Arthur Matthews.

No other members having been nominated up to one month previous to the present meeting, the retiring Vice-Presidents and Members of Council were presented for re-election and declared by the **President** to be duly re-elected.

Andrew Carnegie Scholarships—Since the last General Meeting, the following awards of Andrew Carnegie Scholarships have been made: To Mr. J. P. Hugo (Sheffield University) for research on the tensile properties of aggregates of ferrite and pearlite; to Mr. B. Cina (Sheffield University) for work on the immediate effect of cold-work on the gamma–alpha transformation characteristics of the Fe–Ni–Cr alloys; and to Mr. J. Burke (Liverpool University) for work on the decomposition of the carbide constituent in high-purity cast irons.

Future Meetings—A special meeting will be held in Austria from 5th to 18th September, 1951. Details have been published in the *Journal* for February and May, and a circular will be issued in a few days' time.

The Autumn General Meeting will be held in London on 21st and 22nd November, 1951.

BALLOT FOR THE ELECTION OF MEMBERS

Mr. **P. Walker** and Dr. **D. Binnie,** who were appointed scrutineers of the ballot, reported that the following candidates had been duly elected:

Members

Abraham, Geoffrey Griffith (London); **Aldersley,** Kenneth (Birkby); **Aldridge,** Leonard Ernest (Stourport-on-Severn); **Allbeson,** Ernest N., B.Sc.(Eng.) (Hons.) (Oldham); **Bignell,** John Cyril (London); **Blackwell,** Peter Alan (Watford); **Bloom,** Frederick Kenneth, B.S. (Baltimore, Maryland, U.S.A.); **Boyer,** Francis Andre (Paris); **Brown,** Tom, M.I.Mech.E. (Chesterfield); **Bryant,** Charles Byrn, B.S. (Chicago, Ill., U.S.A.); **Bushell,** Thomas Wyvern, Assoc.Eng. (Middlesbrough); **Campbell,** James (London); **Cavallaro,** Professor Leo (Ferrara, Italy); **Chandler,** Henry Thomas (New York, U.S.A.); **Charlton,** T. W. (Newcastle-on-Tyne); **Clark,** Frank X., B.S. (Springfield, Ohio, U.S.A.); **Coburn,** Frederick Ward, B.S. (Birdsboro, Pa., U.S.A.); **Coche,** Lucien (Paris); **Cole,** Richard S., M.S., Ph.D. (Washington, U.S.A.); **Corney,** Norman Stanley, B.Sc., A.R.I.C. (London); **Cotterill,** E. A. (Rotherham); **Cowan,** William Tait (Musselburgh); **da Costa Lino,** Jorge, B.S. (Volta Redonda, Est. do Rio, Brazil); **Dawkins,** Alfred Ernest, B.Sc.(Hons.), A.R.I.C. (Victoria, Australia); **Dawson,** J. W. (London); **de la Vallee Poussin,** Raoul (Charleroi, Belgium); **Delfos,** F. P. J., B.Sc.(Met.) (Que Que, Southern Rhodesia); **Dick,** Ian Michael (Middlesbrough); **Dickerson,** Julian D., B.S. (Buffalo, N.Y., U.S.A.); **Dunbar,** John, M.I.Mech.E. (Musselburgh); **Dupont,** Max (Paris); **Durrant,** Albert William (London); **Egerton,** George (London); **England,** Harold Haywood (Rotherham); **Farnsworth,** Walter B. (Monessen, Pa., U.S.A.); **Fealdman,** Harold, B.A. (London); **Feely,** Harry M., Jr., B.S. (Monaca, Pa., U.S.A.); **Fields,** Robert William, L.I.M. (Redcar); **Foord,** Thomas Richard, Ph.D., B.Sc. (London); **Foote,** Frederick David (Pittsburgh, Pa., U.S.A.); **Frater,** Edward Charles (Bournemouth); **Freeman,** J. W., Ph.D., B.S. (Ann Arbor, Mich., U.S.A.); **Freeman,** Robert B., Ph.D., M.S. (San Francisco, Calif., U.S.A.); **Frye,** John H., Jr., Ph.D. (Oak Ridge, Tennessee, U.S.A.); **Funder,** Poul Erik (London); **Galton,** Alan Christopher, B.Sc. (Birmingham); **Ghosh,** Prafulla Chandra, B.Sc., B.Met. (Howrah, West Bengal, India); **Giedroyc,** Victor, Ph.D., D.I.C. (London); **Giles,** David J., M.E. (Latrobe, Pa., U.S.A.); **Girling,** William Henry Graham, T.D. (Newcastle-upon-Tyne); **Goddard,** W. T. (Stockton-on-Tees); **Greenwood,** Arthur, A.Met., A.I.M. (Hayes); **Grove,** Hubert A., B.Met.E., M.Sc. (Claymont, Delaware, U.S.A.); **Guthrie,** John, B.Sc. (Motherwell); **Hall,** John Claude, G.I.E.E. (Burton-on-Trent); **Hall,** Kenneth Arnold (Stafford); **Hardy,** John, Assoc.Met., A.I.M. (Swindon); **Harper,** George Cedric (London); **Hellbom,** Kjell Bertil (Söderfors, Sweden); **Hellings,** Charles Edwin (Saltburn-by-the-Sea); **Henschker,** Erhard Rudolf (Bournemouth); **Herbiet,** Henri (Seraing, Belgium); **Horwedel,** Charles Richard, B.Ch.E., M.Sc., Ph.D., Met.E. (Cleveland, Ohio, U.S.A.); **Hunt,** James Bernard, L.I.M. (Bahrein Island, Persian Gulf); **Husemann,** E. W., B.S. (Warren, Ohio, U.S.A.); **Ignatowicz,** Stanislaw, Dipl.Ing. (London); **Jackson,** Paul Louis, B.S.E.Met. (Flint, Mich., U.S.A.); **Jenkinson,** John (Workington); **Jernström,** Anders (Imatra, Finland); **Jewell,** Ronald Colgan, B.Sc.(Hons.), A.R.S.M. (Sheffield); **Jonah,** David Alonzo, Sc.M. (Rhode Island, U.S.A.); **Jones,** Herbert (Milford); **Keyworth,** Alan (Sheffield); **King,** David Ian, B.A. (Hons.) (London); **Kraner,** Hobart McKinley (Bethlehem, Pa., U.S.A.); **Latham,** Peter, B.Sc. (Newport, Mon.); **Laurent,** Paul (Anzin (Nord), France); **Leitner,** Franz, Dr. mont., Dr.techn., Dipl.Ing. (Wartberg/Muerztal, Austria); **Loach,** Reginald Maurice, L.I.M. (Bilston); **Lott,** John Arthur (London); **Nicholson,** George Galloway, M.Eng. (Sheffield); **McCoy,** Frederick A. (Kansas City, Missouri, U.S.A.); **McElderry,** Victor Neville, B.Sc.(Hons.Chem.) (Normanby, near Middlesbrough); **Makikyla,** Esto Penjami (Imatra, Finland); **Markham,** Arthur (Que Que, Southern Rhodesia); **Mulcahy,** Edward William (Wolverhampton); **Pickering,** John William Haswell, B.Sc. (Barnsley); **Pivont,** Maurice (Marcinelle, Belgium); **Polakowski,** Natalis Horacy, Dipl.Ing. (Swansea); **Rocca,** Roberto, D.Sc. (Milan, Italy); **Rose,** Basil Harold, A.I.M. (Birmingham); **Sandberg,** Alexander Christer Edward, B.Sc.(Eng.) (Hons.) (London); **Sanderson,** K., B.Sc. (Rotherham); **Selby,** Leslie Thomas (Croydon); **Shaler,** Amos Johnson, D.Sc. (London); **Sharp,** Victor Albert (Sydney, N.S.W., Australia); **Sheppard,** Norman Frederick, L.I.M. (Hayes); **Siebert,** Benninghoff, B.Sc. (Pretoria, South Africa); **Slocombe,** Cyprian Mitford, Assoc.Eng. (Stocksbridge); **Solt,** Robert, B.Sc.(Eng.) (London); **Souter,** Cecil Charles (London); **Statham,** Ronald Frederick, Assoc.Met. (Stocksbridge);

Stewart, George Wallace, B.Sc., L.I.M. (Staines); **Subramanian,** V. M., B.Sc. (Bangkok, Thailand); **Taylor,** Henry George, D.Sc., M.I.E.E., F.Inst.P. (London); **Thomas,** Duncan (Sheffield); **Thomas,** John Sibbering (Port Talbot); **Thompson,** John G., Ph.D., B.Chem. (Washington, U.S.A.); **Thomson,** Frank Greer (Coatbridge); **Thomson,** Norman David, B.Sc., G.I.Mech.E. (Rotherham); **Tinti,** Rudolf, Dipl.Ing. (Leoben, Austria); **Tucker,** Herbert John Charles (Weybridge); **Turner,** Robert Frederick Angus, A.Met. (Chesterfield); **Violi,** Giuseppe (Genoa, Italy); **Walton,** Ronald Newton (Bombay, India); **Wild,** Richard, B.Sc., Ph.D., A.R.I.C. (London); **Williamson,** A. J., M.S. (Pittsburgh, Pa., U.S.A.); **Willis,** Raymond (Sheffield); **Woolfson,** Harold (B.A.O.R., Germany).

Associates

Armstrong, William (Workington); **Bader,** Michael Geoffrey (Hatfield); **Badham,** Leslie Winnall (Stourport-on-Severn); **Baldwin,** Brian George, B.Sc., A.R.I.C. (London); **Beishon,** R. J. (London); **Brookes,** Kenneth J. A. (London); **Bucklow,** Ian Alfred, B.A. (Cambridge); **Butler,** Ronald David (London); **Butterworth,** Gordon, B.A. (Sheffield); **Catterall,** Graham John (London); **Chawla,** Arjan Dev (Benares, India); **Duckfield,** Baden John (Swansea); **Eaton,** Norman Frank (Swansea); **Edwards,** Derek (Swansea); **Eichen,** Erwin, B.Met.E. (Columbus, Ohio, U.S.A.); **Green,** Paul Richard (Ebbw Vale); **Grimwood,** Kenneth William (Enfield); **Hains,** Jack Whitby, B.A. (Cambridge); **Higgins,** Terence John (Stourport-on-Severn); **Hutchison,** Peter (Birmingham); **Hyam,** E. D., B.A. (Cambridge); **Liddell,** Frank Robert (Birmingham); **Llewelyn,** Meiron (Swansea); **Locke,** Bernard Walter (Croydon); **Loveday,** Kenneth William (London); **Major,** Daniel Christopher (Barnes); **Marsden,** Brian William Hugh (Swansea); **Marsden,** Terence Barclay (Swansea); **Maxwell,** Bernard (Motherwell); **Morgan,** Evan Lewis (Corby); **Morgan,** William Austin, B.Sc.(Hons.) (Cambridge); **Mortimer,** I. G. (Cambridge); **Naylor,** Graham L. (Bilston); **Pearson,** Guy Francis Fisher (Willenhall); **Penry,** William Cedric Rhys (Swansea); **Preston,** Maurice, A.Met., L.I.M. (Sheffield); **Rolls,** Roger (Manchester); **Rowe,** William Moseley (Cardiff); **Sethi,** Rameshwar Singh (Benares, India); **Shakespeare,** Alan Gough, B.A. (Cambridge); **Shami,** Wahid-uz-Zaman, B.Sc. (London); **Warrington,** Peter (Stourport-on-Severn); **West,** John (Newcastle-on-Tyne); **Wilcock,** Jack (Liverpool); **Williams,** Neville Thomas (Swansea); **Wilson,** Alfred Roy (Scunthorpe); **Wood,** Donald Bruce (Gowerton).

The **President** declared the candidates duly elected. They numbered 167, the total membership of the Institute being 4719.

INDUCTION OF THE PRESIDENT-ELECT

Mr. **J. R. Menzies-Wilson** before vacating the Chair introduced the new President, Mr. Richard Mather, adding that he was known to a great many people as one of the leading figures in the steel industry.

Mr. **Richard Mather** in taking the Chair said: "I am very conscious of the honour which you have done me in electing me President, and I wish to record my gratitude to you for doing so. When I joined the Institute about 38 years ago I was much impressed by the stature of the then and previous Presidents, of whom I had some knowledge; so much so that it never occurred to me to expect, or even to hope, that I might become one of their successors. I can do little but say how deeply I appreciate the honour, and that I shall do all in my power to fulfil the responsibilities of this office."

VOTE OF THANKS TO THE RETIRING PRESIDENT

The **President** (Mr. Richard Mather) asked Members to record their appreciation of the services to the Institute of the Retiring President, Mr. Menzies-Wilson, and continued: "Many of you will remember his admirable Address a year ago on iron-ore mining in this country from open workings, a subject on which he has perhaps the most expert knowledge in Britain. His knowledge of it is based not merely on experience in Britain but also on what he has gained from a wide field of investigation of methods of mining ore in other countries. It will be referred to for many years as a standard work on this subject. I want to warn you at once that you will not hear a technical contribution from me, because I do not feel that there is any one subject on which I am capable of giving an address approaching the standard that Mr. Menzies-Wilson reached on his own special subject.

The work of a President is mainly done in Committees and so on, outside the actual meetings of the Institute. I feel sure that to him, along with the Hon. Treasurer, is due a great part of the excellent financial results that Mr. Menzies-Wilson has just summarized for you. Those results are, of course, of great importance to the Institute, as indicating that our finances are on a sound basis. I do not think that the Treasurer is likely to be able to report quite such favourable results a year hence, because certain extra expenses are unavoidably falling upon us; but at least we shall be in a better position to bear the brunt of them because of the very close stewardship which Mr. Menzies-Wilson with the help of the Treasurer, has exercised.

Many of you have come to know Mr. Menzies-Wilson more closely in the course of the past year. I need do no more than ask you to express the results of that knowledge of him by according him a very hearty vote of thanks."

The vote of thanks was carried unanimously, and was briefly acknowledged by Mr. Menzies-Wilson.

PRESIDENTIAL ADDRESS

The **President** (Mr. Richard Mather) then delivered his Presidential Address, at the end of which he added: "I have had, as recently as yesterday, the opportunity of informing the Chairman of the new Iron and Steel Corporation of Great Britain that I was going to say what I have said on the last point mentioned in my Address. I was pleased, and I hope that you will be reassured, to find that he said that he supported entirely what I had written, and that nothing was further from his mind than to attempt to set up any kind of regimentation of technical ideas and technical progress and discussion."

VOTE OF THANKS TO THE PRESIDENT FOR HIS ADDRESS

Mr. **T. M. Service** moved a vote of thanks to Mr. Mather for his very helpful Address and said: "I am particularly interested in what he said about earlier days of the Institute. He has gone back to the time of Sir Lowthian Bell, Sir William Siemens, and others, and it is always fruitful to think of what these men did 'off their own bat,' without any assistance from anybody. I think that that is a very helpful lesson to learn from his Address."

The vote of thanks was carried unanimously, with acclamation, and was briefly acknowledged by the President.

PRESENTATION OF PAPERS

The following papers were presented and discussed (the dates of publication are given in parenthesis):

Wednesday, 30th May

Morning Session

"The Present Position of the Converter Process—Economic Comparison with other Steelmaking Processes," by B. Matuschka (*May*, 1951).

Afternoon Session

Presentation of films by Dr. J. B. Austin on "Study of the Zone in Front of a Blast-Furnace Tuyere by means of High-Speed Motion Pictures and Models."

"Significance of Equilibrium and of Reaction

Rate in the Blast-Furnace Process," by J. B. Austin (*April*, 1951).

Thursday, 31st May

Morning Session

Joint discussion on

"Aspects of the Blast-Furnace Situation in the U.S.A.," by Owen R. Rice.

"Evolution of the All-Carbon Blast-Furnace," by J. H. Chesters, G. D. Elliot, and J. Mackenzie (*March*, 1951).

"Radioactive Indicators for Blast-Furnace Refractory Wear," by E. W. Voice (*February*, 1951).

Afternoon Session

Joint discussion on

"The Smidth Agglomerating Kiln—Plant and Practice at East Moors Works, Cardiff," by W. E. Simons (*January*, 1951).

"Sinter-Making at Appleby-Frodingham," by G. D. Elliot and N. D. Macdonald (*March*, 1951).

"Investigation of the Effects of Controlled Variables on Sinter Quality. Part I—Development of Experimental Sinter Plant and Preliminary Results Using Northants Ore," by E. W. Voice, C. Lang, and P. K. Gledhill (*April*, 1951).

"The Sintering of Northamptonshire Iron Ore —A Production-Plant Study of Factors affecting Sinter Quality," by D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill (*April*, 1951).

Friday, 1st June

Morning Session

Joint discussion on

"Full-Scale Blast-Furnace Trials," by J. A. Bond and T. Sanderson (*May*, 1951).

"Distribution of Materials in the Blast-Furnace. Part III—Further Factors influencing the Distribution of Solids in the Blast-Furnace," by R. Wild (*December*, 1950).

On the motion of the President, a vote of thanks was accorded with acclamation to the authors of the papers presented at the meeting.

The report of the discussions will be published in a later issue of the *Journal*.

PRESENTATION OF THE BESSEMER MEDAL

Sir **Charles Goodeve** presented the Bessemer Medal to Mr. Benjamin Fairless at the General Meeting of the American Iron and Steel Institute held in New York on May 24th, 1951. He said that a hundred years ago people were flocking to London to see the Great Exhibition of 1851. The Great Exhibition gave a tremendous boost to the Industrial Revolution, already in full swing through the development of railways, etc., made from cast and wrought iron, but it was nothing to the boost given by Bessemer himself when he made steel readily available to the engineers of the world.

The Iron and Steel Institute in Great Britain had honoured many of the greatest of the men who have contributed to the progress of iron and steel throughout the world. The list of past American recipients of the medal was an especially impressive one. It began with Peter Cooper, often known as the father of the American Iron Trade, and he was followed by Alexander Lyman Holley, who played a leading part with Kelly in the development of the Bessemer process in America. Then there were Abram S. Hewitt, 'Uncle' John Fritz, and Henry Marion Howe, all recipients of the Medal before the turn of the century. Andrew Carnegie, whose name is known far beyond the realms of the steel industry for the many benefactions he set up, was awarded the Medal in 1906. He was followed by Albert Sauveur, the distinguished metallurgist, and later by Charles M. Schwab, who was known personally by those present. It was a pleasure to see that Eugene G. Grace was present, his contributions to the steel industry, and through that industry to the war effort, were well known on both sides of the Atlantic.

The name of Benjamin F. Fairless was to be added to these. It was probably unnecessary to give reasons why the Council of The Iron and Steel Institute had made this choice. They were proud of the choice because Ben Fairless exemplified in himself just those qualities which were most needed today and were likely to be needed for a long time to come—initiative, technical ability, and courage, qualities that Bessemer possessed.

As President of the great United States Steel Corporation he was closely concerned with some of the most momentous decisions of the present time, among them the decision to send millions of tons of steel to the United Kingdom before Lend-Lease, at a time when we were fighting alone in the war for freedom. The memory of such a great act of friendship at a time like that would live long. Another decision made during the war was to rebuild and expand steelworks at Homestead, at Geneva, and at a number of other places. Yet another decision was to build a new integrated steelworks on the Delaware. These were decisions which provided the allies with the sinews of war, and were examples of initiative which had changed and were changing history.

Sir Charles Goodeve paid tribute to Ben Fairless as a leader, as an engineer, and as an executive, wishing him long life, full strength, and success in his endeavours, and presented him with the Bessemer Medal as a token of esteem.

In accepting the Medal, Mr. **Benjamin Fairless** said that he had been disappointed that circumstances had prevented him from journeying to London to accept the Medal. He had wished to make the journey for many reasons—partly because he had never been to England—partly because he had hoped to visit Wales and to see there the coal-mining regions from which his family came—but mostly because he wished to greet the officers and members of the British Iron and Steel Institute.

Ever since it was first presented to Sir Lowthian Bell, 77 years ago, the Bessemer Medal had been internationally regarded as the greatest honour that any steel man could receive from his colleagues in the industry. He accepted it with genuine humility, and attributed his own accomplishments largely to two things: first, to the loyal and tireless labours of his associates and fellow-workers; and second, to the opportunities and incentives that he had enjoyed in America, that had enabled the American Steel Industry to achieve its spectacular growth and progress in the service of her people.

He spoke of a former Bessemer Medallist, who had received the award at Windsor Castle in the closing year of the last century, Her Majesty Queen Victoria. During her reign the British Iron and Steel Industry made its greatest contribution to mankind—the electrifying surge of scientific and technical progress which sparked the transformation of steelmaking from the crude and isolated operation that it used to be, into the vast, integrated mass-production that it now is. One thing had not, and must not, change, and that was the steadfast determination of the steel men of America and Great Britain to strive constantly in the future, as they had done in the past, for an ever-better product and an ever-greater output of it. He accepted the Medal as a symbol of the 'great fraternity' which united the industries of the two countries, and as a tribute to that God-given combination of opportunity and incentive which was known as the American Way of Life.

IRON AND STEEL
INSTITUTE PAPERS

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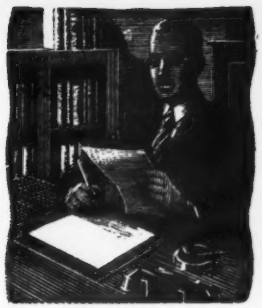

Mechanism and Kinetics of the Chromizing of Mild Steel in Atmospheres Containing Chromous Chloride

By T. P. Hoar, M.A., Ph.D., and E. A. G. Croom, M.A., Ph.D.

SYNOPSIS

It is shown experimentally that 0·1% C mild steel exposed to atmospheres containing chromous chloride at 950–1100° C. becomes coated with a chromium-rich layer, owing to the reactions $CrCl_2 + Fe \rightarrow Cr + FeCl_2$ and, if the atmosphere contains hydrogen, $CrCl_2 + H_2 \rightarrow Cr + 2HCl$. The latter reaction proceeds catalytically on the growing surface. The overall rate of chromizing is limited, in the early stages, by the rates of the reactions (both of which are increased by increase of partial pressure of chromous chloride) and, in the later stages, by the rate of metallic interdiffusion in the growing alloy layer ; the overall rate is at first constant, and later falls off parabolically, with time. The apparent energy of activation of the diffusion process is 57 kg.cal.

Various practical chromizing processes are discussed in the light of the experimental results.

THE first considerable publication on the chromizing process was that of Becker, Hertel, and Kaster,[1] who generated an atmosphere containing chromous chloride vapour by passing a mixture of dry hydrogen chloride and hydrogen over ferrochrome or chromium metal at about 950° C., and from it produced chromium alloy coatings on iron and steel held at rather higher temperatures. Becker, Daeves, and Steinberg[2] heated iron and steel in a pack of refractory material previously impregnated with chromous chloride. Many modifications of these two fundamental methods, and similar processes utilizing atmospheres containing chromous fluoride[3] and iodide,[4] and fused salt baths containing dissolved chromous chloride,[5] have since been described ; Marmach[6] has reviewed the literature. Nevertheless, the only substantial fundamental work on chromizing is the thermodynamic study by Wagner and Stein[7] ; there is very little published work on the mechanism or kinetics. We have discussed elsewhere[8] the reactions thermodynamically possible in the processes utilizing gaseous chromous chloride, and this paper reports experiments designed to establish the reactions that actually occur and to indicate the factors that control the rate of chromizing.

EXPERIMENTAL PROCEDURE

Materials

The single mild-steel sheet used for all the experiments conformed to specification S.84, and had the following analysis : C, 0·1% ; S, 0·05% ; P, 0·05% ; Si, 0·1% ; Mn, 0·21%. Specimens 2 or 3 cm. square were cut from the 20 S.W.G. sheet. They were degreased by swabbing with acetone, pickled for 1 min. in 1 : 1 nitric acid, washed with water, and dried with acetone.

Chromium powder (passing 50 mesh), prepared aluminothermically, was used for generating chromous chloride vapour by direct reaction with hydrogen chloride, and for making chromic chloride. The powder was 99·2% pure, the major impurities being Al, 0·2%, and Fe, 0·35%.

Anhydrous chromic chloride was prepared by passing a stream of dry chlorine over chromium powder heated to about 1050° C. in a long silica reaction tube ; the chromic chloride condensed in the cold end of the tube. Chromous chloride was produced by hydrogen reduction of the chromic chloride during the heating-up period in certain of the chromizing experiments (*see* p. 102).

'Pure' hydrochloric acid (nominally 32% of HCl w/w, sp. gr. 1·16) was used as a source of hydrogen chloride. Hydrogen and nitrogen, used as carrier gases, were of ordinary cylinder quality, and were freed from oxygen by passing through copper gauze at 600° C.

Apparatus

A long tube furnace with two windings was used, so that chromous chloride vapour could be generated

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in the gas stream before it passed over the steel specimen. The furnace and its ancillary gas purification trains, assembled for generation of chromous chloride vapour from the heated liquid and for its entrainment in dry carrier gas, are shown in Fig. 1. The arrangement of 3-way taps enabled the carrier gas to be passed in either direction through the furnace. During the heating-up period (from 20° C. to 950–1050° C. in 2 hr.) hydrogen was passed first over the steel specimen and then over chromic chloride, which was completely reduced to chromous chloride (the reaction begins at about 400° C.). For the chromizing period, the desired carrier gas was passed in the opposite direction, carrying chromous chloride vapour over the specimen ; during cooling, the gas flow was again reversed, to stop chromizing. Tubes and wash-bottles containing silica gel and concentrated sulphuric acid respectively were attached to the furnace exits, to prevent diffusion of air or water vapour into the system.

Figure 2 shows the modification of the apparatus for experiments in which chromous chloride vapour was generated by the reaction of chromium metal with hydrogen chloride. The carrier gas entrained hydrogen chloride and water vapour by passing through two wash-bottles containing fresh concentrated hydrochloric acid at 20° C. ; water vapour was then removed by concentrated sulphuric acid, of which any entrained trace was removed by calcium chloride. The gas was then passed over chromium powder maintained at the desired temperature in the generating part of the furnace, and thence over the steel specimen. During the heating and cooling periods the hydrochloric acid was by-passed.

Gas flow was regulated by a needle valve and was measured by capillary flowmeters utilizing butyl phthalate ; these were calibrated by the passage of gas at volumetrically measured rates.

The temperatures of the gas generation and reaction zones of the furnace were separately measured and regulated to within $\pm 6°$ C. by means of chromel–alumel thermocouples operating automatic temperature controllers. In the first series of experiments, in which chromous chloride vapour was generated from the metal and hydrogen chloride, the very low partial pressure of chromous chloride permitted the use of thermocouples sheathed with silica inside the reaction tube. In the later experiments, atmospheres richer in chromous chloride were used ; they rapidly attack silica, and the thermocouples were perforce placed between the winding tube of the furnace and the reaction tube.

The attack of silica by gaseous chromous chloride was a grave disadvantage of the silica furnace tubes used in early experiments. Mullite ($3Al_2O_3.2SiO_2$) tubes were finally adopted ; the compound is less readily attacked than either of its component oxides.

Determination of Chromium in Chromized Steel

The chromium in chromized specimens was determined colorimetrically. The samples were dissolved in aqua regia ; sulphuric-phosphoric acid mixture was then added, and the solution was evaporated until fumes of sulphur trioxide indicated the complete removal of hydrogen chloride. The procedure developed by Haywood and Wood[9] was followed for the subsequent oxidation of Cr^{+++} with ammonium persulphate. Dichromate was estimated with a Spekker photoelectric adsorptiometer, calibrated with standard solutions of potassium dichromate.

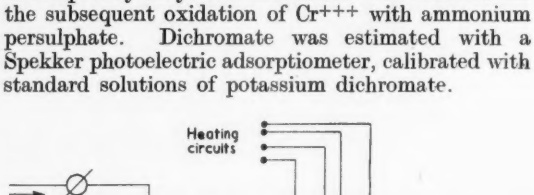

Fig. 2—Modified apparatus for chromizing with atmospheres generated by reaction of hydrogen chloride with chromium metal

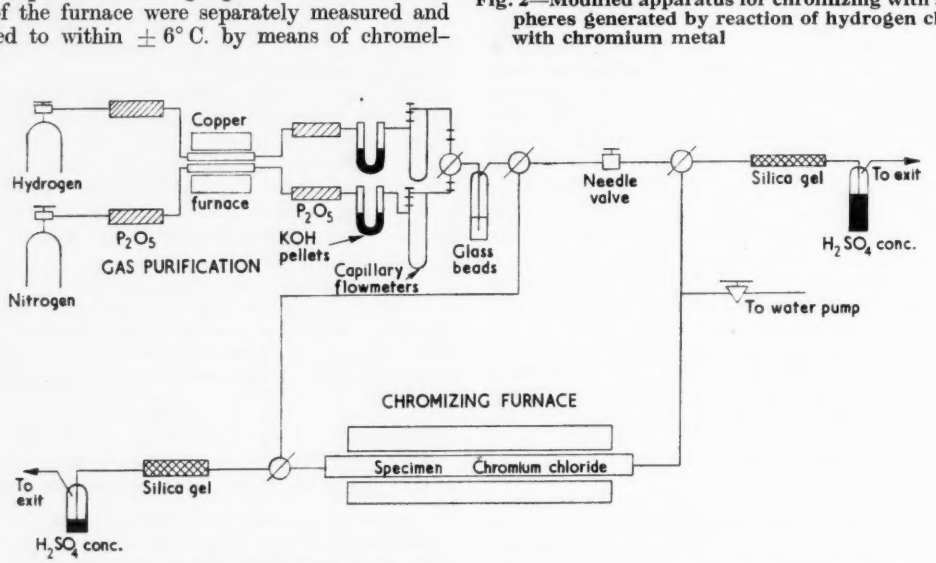

Fig. 1—Apparatus for chromizing with atmospheres generated by entrainment of vapour from heated chromous chloride

RESULTS AND INTERPRETATION

Structure of Coatings

All the chromized coatings were of usual structure, with a thick outer layer of columnar α crystals, and an inner, very thin, layer of transformed γ-alloy, similar to that illustrated by Campbell, Barth, Hoeckleman, and Gonser[5] for chromized coatings formed in the liquid-salt-bath process. There was usually a slight variation of coating thickness along the length of the specimen, owing to chromium uptake from the chromizing vapour as it flowed past the specimen in the furnace (*see* Fig. 3). The total depth of the chromized metal at the end of the specimen nearest the incoming gas in the furnace (as indicated by etching in 2% nital) has been used in the following discussion of the influence of experimental variables on coating thickness.

Analysis of a number of coatings, stripped by dissolution of the underlying metal in dilute nitric acid, gave values for chromium content ranging from 18·5% to 22·8%, with a mean of 20·0%. These coatings were produced by treatments of 2–15 hr. at temperatures from 970° to 1050° C., and there was no correlation between the mean chromium content of the coating and either time or temperature of treatment. It is likely that all chromized coatings on 0·1% C mild steel, produced by gaseous treatment within these ranges of time and temperature, have mean chromium contents of 20 ± 3%.

Influence of Carrier Gas Composition and Rate of Gas Flow on Chromium Uptake

Preliminary experiments with hydrogen, nitrogen, and various mixtures as carrier gas showed that chromizing was little affected by variation of carrier gas between 100 and 67% of hydrogen, except that the nitrogen-containing mixtures led to rather more even coatings, doubtless owing to the better mixing of the heavy chromous chloride vapour with a heavier carrier gas. In hydrogen-free nitrogen, chromizing was irregular and slow; traces of oxygen may have interfered with the volatilization of the chromous chloride, by producing less volatile oxy-compounds. For the main experiments pure hydrogen was used, so as to have conditions as simple as possible.

Results of experiments with different rates of flow of hydrogen as carrier (between 3 and 10 l./hr.) showed no appreciable difference of chromizing rate, even with the poorest chromizing atmosphere used, *i.e.*, that

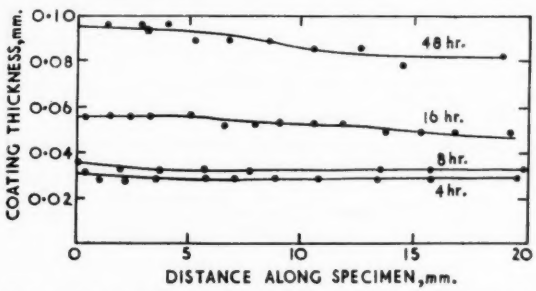

Fig. 3—Variation of coating thickness along length of specimen. Chromizing with chromium and H_2–HCl gases, at 1000° C.

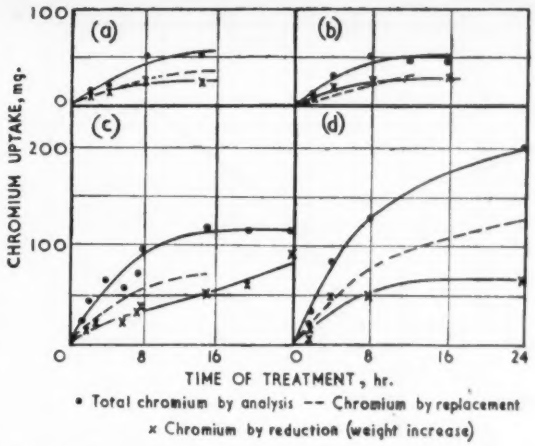

Fig. 4—Influence of time on weight gain and on chromium uptake at : (*a*) 970° C., (*b*) 1000° C., (*c*) 1050° C., (*d*) 1100° C.

produced from chromium metal. A gas flow of 6 l./hr. was adopted in all subsequent experiments.

Influence of Time and Temperature on Chromium Uptake and Iron Loss

An atmosphere containing chromous chloride was generated by passing purified hydrogen through nominally 32% w/w hydrochloric acid at 20° C., drying the issuing gas with concentrated sulphuric acid, and passing it over chromium powder at 950° C. Figure 4 shows the gain in weight of a series of specimens treated in this atmosphere for different periods (up to 24 hr.) at 970°, 1000°, 1050°, and 1100° C., and also shows the chromium uptake as determined by analysis. The iron loss is given by the difference of these amounts. The chromium uptake is always considerably greater than the iron loss corresponding to the interchange reaction $CrCl_2 + Fe \rightarrow Cr + FeCl_2$, and evidently the extra chromium arises from the catalytic reduction $CrCl_2 + H_2 \rightarrow Cr + 2HCl$, taking place on the metal surface. Since the chromium-uptake/iron-loss ratio for the interchange reaction is $52/56 = 0·93 \simeq 1$, the gain in weight of the chromized specimens is, within experimental error, equal to the weight of chromium formed by the reduction reaction, which may be seen to account for about half of the total chromium uptake.

The total chromium uptake, and that part of it due to the reduction process, are both approximately proportional to the time of treatment for short times, but the relationships become roughly parabolic for longer treatments. This indicates that, in the early stages, the rates of chromium uptake by both interchange and reduction are limited mainly by the rates of the interchange and reduction reactions on the surface, but that, in the later stages, the rates are limited mainly by the rate of interdiffusion of chromium and iron, which diminishes with increase of coating thickness. Obviously, the rate of the interchange reaction must eventually be limited by the amount of iron available in the growing surface, which decreases with increase of coating thickness. The fact that the reduction

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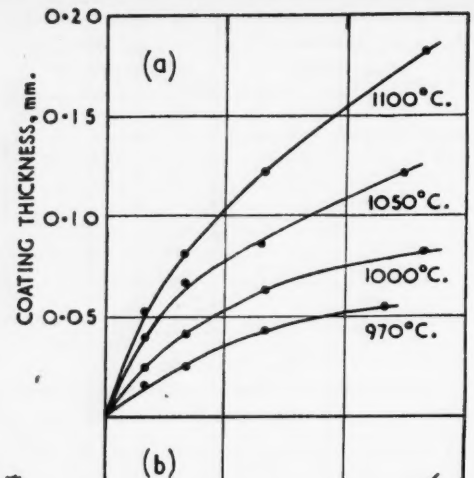


Fig. 5—Influence of time and temperature on coating thickness: (*a*) Plotted directly; (*b*) plotted as (thickness)² *vs.* time

reaction, in which iron is not a reactant, also slows down as chromizing proceeds, indicates that its *net* rate decreases with increase of chromium content of the chromium–iron alloy surface on which it takes place. This may be merely the result of the increase in rate of the reverse reaction: however, the dependence of the *absolute* rate of a catalytic reaction on an alloy surface on the alloy composition has been demonstrated for other reactions and other alloys by Schwab and his co-workers;[10,11] both the free energy and the entropy of activation are considerably influenced by the electronic state of the alloy, which is a function of its composition.

Influence of Time and Temperature on Coating Thickness

Figure 5*a* shows the coating thickness determined on the series of specimens just discussed, plotted against time of treatment at 970°, 1000°, 1050°, and 1100° C. In the early stages, the coating thickness is approximately proportional to time of treatment, but the relationship becomes parabolic after 2–4 hr., as shown in Fig. 5*b*.

A very approximate treatment of the coating-thickness/time relationship, based on Fick's law, has been used by Campbell *et al.*[5] to interpret their similar results for salt-bath chromized coatings. If C_0 is the concentration (assumed constant) of the diffusing substance in the surface of the coating, C its concentration at depth x after time t, and D the metal interdiffusion coefficient (assumed constant with composition), then for diffusion into a semi-infinite solid for which Fick's law applies

$$1 - \frac{C}{C_0} = \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{Dt}}} e^{-y^2} dy. \quad \ldots\ldots\ldots\ldots (1)$$

Since, in the Gauss integral, $x/2\sqrt{Dt}$ is a number,

$$x^2 = 4ADt. \quad \ldots\ldots\ldots\ldots (2)$$

where the constant A depends upon the value of C/C_0, and may be found from tables of the Gauss integral. Hicks[12] has shown that, for chromized coatings formed by chromium in contact with iron at 900–1000° C., the chromium content falls continuously from about 70% in the surface to about 14%, after which it drops relatively rapidly to zero (the discontinuity is caused by the $\alpha \rightarrow \gamma$ transformation at 14% of chromium, and by the relatively slow inward diffusion of chromium in the interior γ-iron). Thus, if we take $C = 14\%$ and $C_0 = 70\%$, $C/C_0 = 0{\cdot}2$, from which $A = 0{\cdot}82$; if we alternatively assume that $C_0 = 100\%$, then $A = 1{\cdot}1$; and if we identify x with the coating thickness, equation (2) becomes approximately:

$$x^2 = 4Dt. \quad \ldots\ldots\ldots\ldots (3)$$

which may be used to estimate the interdiffusion coefficient D.

The values of D so calculated from the gradients of the lines in Fig. 5*b* are given in Table I; they agree well with the estimates of previous workers, shown in the Table for comparison.

Equations (2) and (3) rest on the assumption

Table I

THE DIFFUSION CONSTANT FOR THE INTERDIFFUSION OF CHROMIUM AND MILD STEEL OR IRON

Material	Temp., °C.	Diffusion Constant, cm.² sec.⁻¹ × 10⁻¹⁰	Source
Mild steel S.84 (0·1% C)	970 1000 1050 1100	1·55 3·0 6·9 14·7	The present work
Iron	1100	8–12	Grube[13]
Armco iron	1150 1300	Approx. 17 Approx. 145	Calculated from the thickness results of Bardenheuer and Müller[14]
Armco iron	1000 1100 1200	3·5 25 97	Campbell, Barth, Hoeckelman, and Gonser[5]

that the Gauss integral, valid for diffusion into a semi-infinite solid, may also be used when a coating of finite thickness is considered. Although this assumption is clearly wrong, the *form* of equations (2) and (3) is correct, since the dimensions of D are cm.^{2} sec.$^{-1}$. Thus the parabolic relationship is to be expected, but the absolute values of D deduced from the parameters of the equations may be in error by a factor of two or three.

In Fig. 6, the plot of $\log_{10} D$ against $1/T$ (where T is the absolute temperature) is rectilinear ; it leads to an apparent energy of activation for the diffusion process of 57 kg.cal. This value (which is of the order to be expected by analogy with other metal interdiffusion processes) is in excellent agreement with that which may be calculated by the same method from the results of Campbell *et al.*[5] for salt-bath chromized coatings on Armco iron, namely, 58 kg.cal. Provided that the parameter A in equation (2) is independent of temperature, its value does not influence the value of the apparent energy of activation obtained.

Influence of the Partial Pressure of Chromous Chloride on the Chromizing Rate

The results given in Fig. 7*a* show the chromium uptake in a series of experiments in which a relatively high partial pressure of chromous chloride was obtained in the chromizing gas by vaporization of the liquid maintained at 1000° C. ; comparable results for the HCl–Cr process are also given. The coating thicknesses obtained in the same experiments are shown in Fig. 7*b*, together with those obtained by the HCl–Cr process, and some comparative results of Campbell *et al.*[5] for the salt-bath chromizing of a steel of specification SAE 1015 (very similar to the S.84 steel used in our experiments). Similar chromium-uptake and coating-thickness results for 3-hr. treatments on 3-cm. square, 20 S.W.G. specimens in atmospheres containing various partial pressures of chromous chloride, are given in Table II.

The practical difficulty of containing atmospheres rich in chromous chloride confined these experiments to relatively short-time treatments, and precludes any great precision in the results. Nevertheless, it is clear

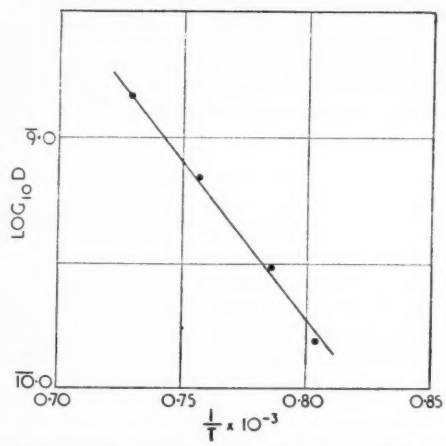
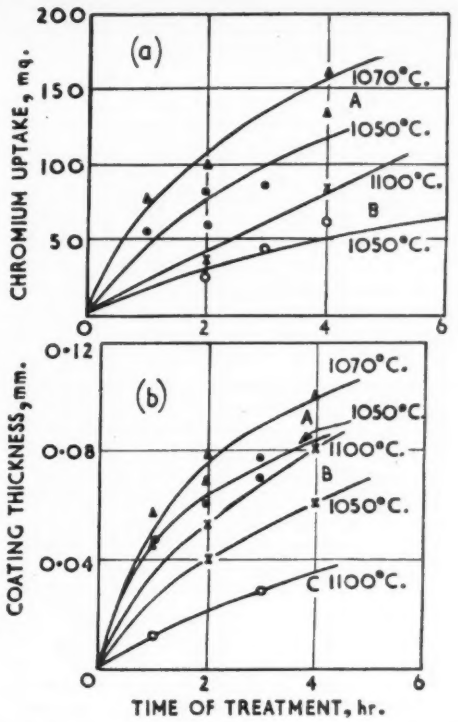


Fig. 6—Influence of temperature (T° K.) on the apparent metal interdiffusion coefficient (D cm.^{2} sec.$^{-1}$)



A. Chromizing atmosphere generated from liquid $CrCl_2$ at 1000° C. ; $p_{CrCl_2} = 0{\cdot}0245$ atm.

B. Chromizing atmosphere generated from HCl and Cr : $p_{CrCl_2} \simeq 0{\cdot}0005$ atm.

C. Salt-bath process[5]

Fig. 7—Influence of partial pressure of chromous chloride, at various temperatures, on: (*a*) Rate of chromium uptake; (*b*) rate of increase of coating thickness

that increase of chromous chloride partial pressure in the chromizing vapour leads to increase in the rate of chromium uptake and of coating thickening in the early stages of chromizing ; this is further evidence that the overall rate is here limited mainly by the net rates of the interchange and reduction reactions, rather than by the rate of metal interdiffusion. However, the curves in Figs. 7*a* and *b* show that chromous chloride partial pressure ceases to influence the overall

Table II

INFLUENCE OF PARTIAL PRESSURE OF CHROMOUS CHLORIDE ON CHROMIZING RATE OF MILD STEEL (S.84)

Temperature of Chromous Chloride, ° C.	Vapour Pressure of Chromous Chloride, atm.	Reaction Temp., ° C.	Chromium Uptake, mg.	Coating Thickness, mm.
950	0·0108	1020	51	0·028
1020	0·0331		75	0·040
900	0·0045	1050	57, 66	...
1000	0·0245		84, 125	...

rate (at temperatures of 1050–1100° C.) when the coating thickness has reached about 0·06 mm.; beyond this stage, the rate of metal interdiffusion limits the overall rate.

DISCUSSION

The claim that chromized coatings on iron and steel can be formed without sensible change of weight or dimensions of the specimen, although probably true for coatings formed solely by the interchange of iron and chromium in non-reducing environments such as the salt bath, is shown by the present results to be invalid for coatings formed in reducing atmospheres containing hydrogen. The increases of weight, which have also been found under rather different conditions,[15,16] are undoubtedly caused by the catalytic reduction of chromous chloride by hydrogen.

For rapid chromizing and for coatings of the highest chromium content, where dimensional or weight changes are not important, it is, however, desirable to use an environment that is reducing and in which the chromous chloride activity is high. The relatively small rates of chromizing in the salt-bath process, as found by Campbell *et al.*[5] (*see* Fig. 7*b*), are the result of the absence of reduction by the environment, and of the necessarily low chromous chloride activity in the bath—this is equal to its activity in the overlying vapour, and must be low if loss of chromous chloride by vaporization is to be avoided. For high chromous chloride activities at the temperatures needed for fairly rapid rates of reduction, interchange, and diffusion, it is essential that the salt be used in the vapour phase, and this introduces the difficulty of the containing of atmospheres having high partial pressures of chromous chloride. This difficulty has been mentioned (*see* p. 105) as the probable cause of uncertainties in the results of experiments in which chromizing atmospheres are generated by vaporizing liquid chromous chloride in a stream of hydrogen. It has been partially resolved in practice by packing the work to be chromized with porous ceramic impregnated with chromous chloride, in a single box; even so, the choice of materials for the box is limited, and none is entirely satisfactory.

The rate of increase of coating thickness becomes mainly limited by metal interdiffusion when the thickness has reached about 0·06 mm. For especially thick coatings, therefore, the method of chromizing will have relatively little influence on the long time required for their formation. For thin coatings, however, where the rate of production depends so markedly on the environment, the pack or gas-flow methods can produce coatings of specified thickness in considerably less time than the salt-bath process—a somewhat unfortunate conclusion in view of the potential mechanical advantages of a simple dipping process for short-time treatments.

A more subtle difficulty exists in the original process,[1] where chromizing atmospheres are generated by passing hydrogen-chloride/hydrogen atmospheres, made by entrainment from aqueous hydrochloric acid, over heated chromium. In the series of experiments on this process here reported, hydrogen was passed through a fairly large volume (about 250 ml.) of nominally 32% w/w hydrochloric acid maintained at 20° C. Over this acid, the partial vapour pressure of hydrogen chloride is 23·5 mm. of Hg, and that of water is 4·5 mm.; the *dried* hydrogen-chloride/hydrogen mixture entering the generating furnace therefore has partial pressures $p_{HCl} = 0{\cdot}0311$ atm. and $p_{H_2} = 0{\cdot}969$ atm. For the reaction $Cr_{solid} + 2HCl_{gas} \rightarrow CrCl_{2gas} + H_{2gas}$, the data as summarized by Doerner[17] lead to

$$\Delta G^\circ = 14{,}170 - 5{\cdot}47T \log T + 1{\cdot}91 \times 10^{-3} T^2 + 2{\cdot}589T,$$

from which we may calculate $Kp_{950^\circ C.} = 1{\cdot}2$. The more recent experiments of Wagner and Stein[7] lead to $Kp_{879^\circ C.} = 0{\cdot}4$ and $Kp_{930^\circ C.} = 0{\cdot}5$, from which we may estimate $Kp_{950^\circ C.} = 0{\cdot}54$. Using the latter value we find that the partial pressures in the gas leaving the generating furnace and entering the chromizing furnace are $p_{CrCl_2} = 0{\cdot}00050$ atm., $p_{HCl} = 0{\cdot}0300$ atm., and $p_{H_2} = 0{\cdot}97$ atm. For the gas flow of 6 l./hr. (at a temperature of 20° C. and a pressure of 760 mm.) this gives the supply of chromous chloride to the chromizing furnace as about 16 mg./hr., equivalent to about 6·7 mg./hr. of chromium, which is too small to account for the faster observed rates of chromium uptake (*see* Fig. 4).

The discrepancy may arise partly from error in the value of $Kp_{950^\circ C.}$, but it is probably mainly caused by error in the estimate of the partial pressure of hydrogen chloride entering the generating furnace. The partial pressure of the gas over concentrated aqueous hydrochloric acid at 20° C. changes very rapidly with liquid composition; whereas for 32% w/w acid it is 23·5 mm. of Hg, for 34% it is 50·5 mm., and for 36% it is 105·5 mm. Analysis of several samples of nominally 32% w/w acid gave results varying between 33 and 35%. Since the partial pressure of chromous chloride produced in the generating furnace is almost proportional to the square of the partial pressure of hydrogen chloride, these upward variations in the composition of the hydrochloric acid used could account for much more rapid supply-rates of chromous chloride than that calculated above for true 32% w/w acid. As we have shown, the rate of chromizing is dependent on the chromous chloride partial pressure only in the early stages, so that the experimental variations just discussed do not invalidate the determinations of the rate in the later stages, where it is limited by the rate of metal interdiffusion.

The marked dependence of the original process[1] on the hydrochloric acid concentration was undoubtedly its greatest practical disadvantage, and accounts for a number of unsuccessful experiments and attempts to carry it out industrially.

CONCLUSIONS

(1) Mild steel (0·1% C) exposed to atmospheres containing chromous chloride at 950–1100° C. becomes coated with a chromium-rich layer produced by the interchange reaction $CrCl_2 + Fe \rightarrow Cr + FeCl_2$ and (when hydrogen is also present in the reagent atmosphere) by the reduction reaction $CrCl_2 + H_2 \rightarrow Cr + 2HCl$, which proceeds catalytically on the growing surface.

(2) In the early stages of chromizing, the overall rate of chromium uptake is constant with time and is limited by the rates of the interchange and reduction reactions, both of which are increased by increase of

the partial pressure of chromous chloride in the atmosphere.

(3) In the later stages of chromizing, the overall rate of chromium uptake diminishes with time according to a parabolic law ; it is limited by the rate of the metal interdiffusion of chromium and iron, because this limits the concentration of iron in the growing surface available for interchange, and because the reduction reaction is less well catalysed by surfaces lower in iron.

(4) The apparent energy of activation for the metal interdiffusion process is 57 kg.cal.

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Disintegration of 45–50% Ferro-Silicon and the Generation of Poisonous Gases

By A. K. Prestrud

SYNOPSIS

A war-time experiment with ferro-silicon showed an uneven distribution of the different elements in the cast. The analytical figures are compared with data from the iron–silicon equilibrium diagram. The influence of aluminium on the disintegration of certain grades of ferro-silicon with the evolution of phosphine is discussed, and the cause of disintegration is suggested.

Discussion among Norwegian producers of ferro-silicon, on why certain alloys containing about 50% of silicon disintegrate and give off phosphine gas, prompted the author to prepare the following notes on some experiments that he had made during the war. In war-time the supply of raw materials was difficult, and materials of inferior quality had to be used. The rock and coke available contained large amounts of alumina, and the alloy produced was not so solid as that made before the war ; it had a tendency to disintegrate, and smelt of phosphine.

EXPERIMENTAL PROCEDURE

A pit was dug in the ground and lined with fire-bricks covered with a coating of plaster, making a truncated-cone-shaped mould. After thorough drying by firing, approximately 45 cwt. of alloy were run into the mould, covered with sand and sheet iron, and allowed to cool slowly for nine days. A large vertical crack through the centre of the cast was then observed, in which small detonations were occurring ; these were assumed to be caused by the ignition of escaping phosphine gas on coming into contact with the air. The cast (*see* Fig. 1) had an upper diameter of

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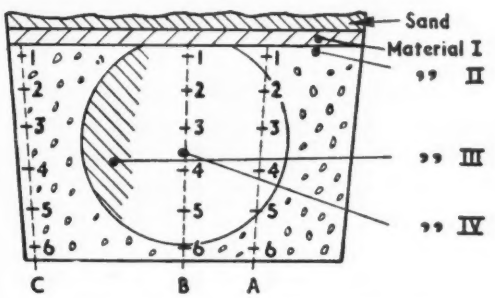

Fig. 1—The cooled ferro-silicon cast

43 in., a lower diameter of 39 in., and a vertical height of 26 in. The outer part was porous, whereas the centre (shown inside the circle in Fig. 1) seemed to be dense and without pores.

On the tenth day, samples were taken of the materials from the positions marked in Fig. 1 :

Material I—Cake of slag on top, 2½–2¾ in. thick
" II—Metal adhering to the top cake
" III—Coating material in the vertical crack
" IV—Disintegrated metal from the centre of the cast.

In addition, three series of samples, *A*, *B*, and *C*, each comprising six specimens, were taken from the positions also shown in Fig. 1. Specimens 2, 3, and 4 of series *B*, disintegrated immediately.

After about two or three weeks, the cast material was sorted into two groups (*a*) disintegrated metal, 11 cwt. (about 25% of the cast), and (*b*) solid metal, 34 cwt., and samples were taken from each.

ANALYTICAL RESULTS

The analyses of all the samples are recorded in Table I. The figures for series *A*, *B*, and *C* show that the aluminium, titanium, and silicon contents increased in the core of the cast, whereas the material richest in iron was found in the outer shell, which had solidified before the interior. The central part seemed to be enriched in phosphorus and calcium. Chromium was present in such small amounts that the segregation effect, if any, was not apparent ; the behaviour of manganese was also uncertain.

Material III, consisting of metal with a white coating, was taken from the vertical crack in the cast where the explosions had occurred. This sample was

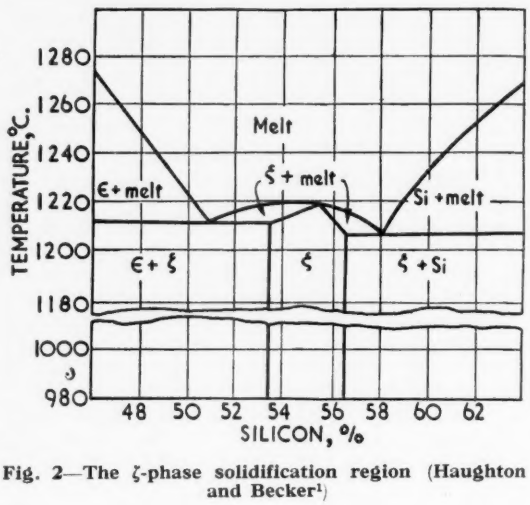

Fig. 2—The ζ-phase solidification region (Haughton and Becker[1])

Table I

ANALYSES OF SAMPLES FROM A FERRO-SILICON CAST

Test Series	Specimen No.	Analysis, %								Ratio Si/Fe	State of Sample
		Si	Fe	Al	Ti	Cr	Mn	Ca	P		
A	1	50·50	47·70	0·66	0·17	0·02	0·42	0·01	0·038	1·058	Solid
	2	50·50	48·00	0·83	0·23	0·03	0·42	0·05	0·036	1·051	,,
	3	50·50	48·00	0·88	0·23	0·04	0·45	0·04	0·040	1·051	,,
	4	50·00	48·50	0·77	0·18	0·04	0·36	0·02	0·045	1·031	,,
	5	46·50	52·50	0·53	0·13	0·03	0·36	0·01	0·035	0·885	,,
	6	44·00	55·20	0·38	0·07	0·02	0·37	Trace	0·039	0·800	,,
B	1	49·35	47·60	1·04	0·60	0·07	0·63	0·11	0·036	1·036	Solid
	2	48·50	44·70	3·24	1·95	0·20	1·17	0·14	0·035	1·085	Disintegrated
	3	49·70	46·00	1·92	1·00	0·12	0·90	0·14	0·035	1·080	,,
	4	49·40	47·60	1·72	0·43	0·10	0·62	0·07	0·041	1·040	,,
	5	46·50	51·60	0·95	0·23	0·06	0·50	0·05	0·047	0·900	Solid
	6	45·00	54·58	0·58	0·13	0·04	0·36	0·04	0·030	0·825	,,
C	1	42·25	56·00	0·60	0·09	0·04	0·34	0·02	0·038	0·755	Solid
	2	44·90	53·80	0·60	0·15	0·04	0·28	0·01	0·038	0·835	,,
	3	44·50	54·50	0·44	0·11	0·03	0·33	0·03	0·030	0·817	,,
	4	45·00	54·00	0·50	0·14	0·03	0·35	0·02	0·038	0·834	,,
	5	42·50	56·50	0·53	0·09	0·03	0·37	0·04	0·037	0·753	,,
	6	42·00	57·40	0·27	0·07	0·03	0·35	0·01	0·030	0·732	,,
Average for the cooled cast		47·34	50·67	0·78	0·23	0·05	0·39	0·04	0·020	0·933	
Cleaned alloy		46·50	51·80	0·55	0·15	...	0·36	0·02	0·024	0·900	Solid
		50·00	47·00	1·20	0·50	...	0·50	0·10	0·008	1·064	Disintegrated
Material II		49·50	47·30	1·35	0·33	...	0·59	0·18	0·050	1·046	Solid
,, III*		46·20	44·50	3·00	0·57	...	1·03	0·44	Trace	1·038	,,
,, IV		49·40	46·50	1·96	0·55	...	0·73	0·07	0·042	1·062	Disintegrated
		SiO_2	Al_2O_3	TiO_2	CaO	MgO	SiC	P	Metal		
Material I (slag)		26·85	27·50	0·15	36·40	1·60	1·50	0·03	5·20		

* Sample contained some oxide

exceptionally high in aluminium and low in phosphorus ; it also contained some oxide, possibly Al_2O_3 formed by the decomposition of aluminium phosphide by the action of moisture.

Constitution of Iron–Silicon Alloys

The compounds and phases found in the iron–silicon alloys (46–64% of silicon) are shown in Fig. 2, which is a reproduction of part of Fig. 1 of a paper by Haughton and Becker.[1] In the 45–50% silicon region, only the two compounds FeSi (ε), with 33·44% of silicon, and Fe_2Si_5 (ζ), with 55·68% of silicon, are relevant. They form a eutectic, with about 50·5–51% of silicon.

When liquid 45–50% ferro-silicon is allowed to cool slowly enough for equilibrium to be attained, the ε-phase is deposited until the composition of the liquid phase reaches about 51% of silicon ; after this, the ε–ζ eutectic forms. The figures in Table I for series *A*, Nos. 5 and 6, and for series *C*, show that the alloy in the outer parts of the cast contains the highest proportion of the iron-rich ε-phase. Allowing for the presence of impurities, series *B* is seen to extend into the composition range within which the eutectic forms.

Discussion of the Analytical Results

The silicon content (50·5–51%) of the eutectic mixture corresponds to a Si/Fe ratio of 1·02–1·04. For all the disintegrated samples the ratio was higher, except for No. 4 of series *B*, for which it was exactly 1·04. All the metal that crumbled before or during sampling contained more than 1·70% of aluminium. Four weeks after tapping, about one-quarter of the cast had disintegrated, and this metal contained an average of only 1·20% of aluminium.

This suggests that disintegration occurs when the Si/Fe ratio is greater than 1·04, that it proceeds immediately when the aluminium content exceeds 1·7%, and that breakdown is delayed when the aluminium content is below 0·75%. Relating the silicon plus aluminium content to the quantity of iron, by using the ratio (Si + Al)/Fe, a closer fit to the experimental results and a more accurate limit may be obtained ; the results indicate that disintegration is delayed for a (Si + Al)/Fe ratio of between 1·05 and 1·1, and is immediate when the ratio exceeds 1·1. These figures, however, are based only on the experiment described, and should be confirmed by further tests ; the rate of cooling of the alloy, for instance, may have an effect on lattice tension and disintegration.

DISINTEGRATION PHENOMENON

Haughton and Becker[1] stated that the presence of aluminium in small amounts affects the microstructure of the iron–silicon alloys, especially in the central part of the diagram. They remarked that " In the alloy with 39% of silicon (which contained about 0·4% of aluminium) no sign of eutectic structure could be found, the areas which should have appeared as eutectic having the appearance of homogeneous solid solutions," also that the ζ-phase was friable, so that its microscopical identification was difficult.

It is the author's opinion that the aluminium may to some extent prevent or delay the eutectic segregate by forming an undercooled solid solution, supposedly identical in microstructure with the ε-phase ; this solid solution, however, is unstable, and the ζ-phase finally develops. During this transformation the atomic arrangement changes from the cubic to the tetragonal system, the density of the former[2] being 6·05 and of the latter[3] theoretically 5·02. The transformation is consequently accompanied by an increase in the specific volume, and this is believed to be the reason for the break-up of the eutectic matrix. The difference in the densities may be a little less than is indicated here, as some of the iron atoms are replaced by the lighter silicon atoms in the ε lattice, to conform to the composition of the eutectic region.

Source of the Phosphine

The disintegrated alloy contained the highest amount of aluminium, and the phosphorus content apparently increased as the aluminium content increased. The highest phosphorus content was found in those samples which were ' about to disintegrate ' (series *A*, Nos. 3 and 4, and series *B*, Nos. 4 and 5). The sample containing the least phosphorus came from material III, in which it is assumed that the phosphide had decomposed before the sample was drawn. This seems to confirm the earlier hypothesis that the phosphine is generated by the decomposition of aluminium phosphide in moist air, as does also the well-known fact that disintegrating alloys smell more strongly of phosphine than does solid metal.

CONCLUSIONS

(1) The different elements were found to be unevenly distributed in the cooled cast. The aluminium, titanium, silicon, and phosphorus contents were greater in the core, whereas iron-rich components accumulated in the outer parts of the cast.

(2) The disintegration of some grades of 45–50% ferro-silicon is connected with a polymorphic transformation in which aluminium plays an important rôle.

(3) The evolution of phosphine from the disintegrated metal is correlated with the aluminium content. The earlier hypothesis that phosphine is generated by the decomposition of aluminium phosphide under the influence of moisture is apparently confirmed.

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DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

SPECIAL MEETING IN GLASGOW, 1950

A SPECIAL MEETING OF THE IRON AND STEEL INSTITUTE was held in Glasgow from Tuesday, 12th September, to Friday, 15th September, 1950, by invitation of the West of Scotland Iron and Steel Institute. A joint session for the discussion of technical papers was held with the West of Scotland Iron and Steel Institute on Tuesday, 12th September, 1950, at the Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow. A full programme of visits to works and excursions to places of interest was arranged for Members and Ladies.

The Report of the Meeting was published in the September issue of the *Journal* (vol. 169, p. 1).

Discussion on the Paper—

THE REDUCTION OF LUMP ORES* *By R. Wild and H. L. Saunders*

Dr. **H. L. Saunders** presented the paper.

Mr. **R. P. Towndrow** (Colvilles, Ltd.): Unfortunately the nature of the work being carried out in the laboratories at South Kensington is such that the results produced give quantitative confirmation of the very worst of the qualitative apprehensions of blast-furnace operators, and this paper is no exception to that general rule. Most of us who are making basic pig iron from imported ores are faced with the problem of smelting mixtures of comparatively porous and easily reduced hematite-class ores with the dense less easily reduced Swedish-type ores. Under today's conditions the latter type of ore is becoming increasingly predominant in the burden, and in addition, the preparation of such ores for smelting involves the screening-out and sintering of fines; in general, sinter tends to be allied in nature with the materials less easily reduced in the furnace. It appears desirable that all the materials should arrive at specific levels in the furnace in substantially similar states of reduction and preheat, and it is this aspect of the furnace operator's problem which the present paper seeks to clarify.

In the past it was considered, before this paper poured cold water on such hopes, that this object could be achieved in one or both of two ways, namely, (*a*) by a preferential sizing of the ores so that the denser ores could be crushed to a smaller size, thereby affording them an equal opportunity for reduction and preheating to that enjoyed by the larger fragments of the more porous and easily reducible hematite ores, or (*b*) by selective burdening to ensure that the furnace was burdened substantially either with the dense ores or the porous ores predominating. The furnace burdened with the dense ores would then be operated at a slower rate in order to allow time for the chemical and thermal preparation of the burden.

From the authors' results it seems that there is relatively scant hope of either of these methods bearing a full measure of success. If the dense ores are to be crushed to the sizes indicated it is probable, as the authors point out, that the amount of fines produced would be greater than could economically be sintered under present conditions. Secondly, the fact that gaseous reduction proceeds to only a very limited depth in the ore makes it unlikely that a furnace burdened solely with dense ores could be economically operated at a very slow rate of driving such as would permit complete gaseous reduction. It therefore appears that the story is not yet finished.

Referring for a moment to the utilization of carbon in the blast-furnace, it is clear that a molecule of carbon engaging in the reduction of iron oxide directly is twice as efficient from the chemical point of view as a molecule of carbon which has first undergone partial oxidation by the blast to carbon monoxide. On the other hand, from the thermal point of view, the direct reaction between carbon and iron oxide absorbs heat in a region of the furnace where maximum heat liberation above the critical temperature is most necessary. Bearing in mind the limiting CO/CO_2 ratios attainable in practice it would seem that under certain conditions the complete gasification of carbon at the tuyeres, in a quantity to provide sufficient carbon monoxide for the complete reduction of the charge, would liberate more heat than is required by the process. In that case, therefore, a certain

* *Journal of The Iron and Steel Institute*, 1950, vol. 165, pp. 198–214.

proportion of direct reduction will be inevitable. The balancing point at which direct reduction becomes uneconomical depends very largely on the constitution of the burden and upon the heat requirements at various temperature levels to allow the different stages of the process to continue, an aspect which has been recently considered by Taylor.* We now know a great deal about the reactions between iron ores and reducing gases up to temperatures of 900° C., and our knowledge of the reactions occurring at higher temperatures where the materials become liquefied is rapidly increasing ; there is still, however, a region of gaseous reaction at temperatures between 900° and 1100° C. which is comparatively unexplored. The experimental difficulties in investigating reactions at these temperatures at an appropriate gas velocity are very large, but it can perhaps be presumed that some reaction speeds would be very much accelerated in this region. When this gap in the knowledge is filled it may perhaps explain why the performance of furnaces operating on mixtures of porous and dense ores is rather better than might be anticipated from the present studies, which appear to indicate that with materials of the sizes normally charged almost the whole of the dense ores would require to be reduced by the direct reaction between carbon and iron oxide. Nevertheless, some indication of the magnitude of the effect produced by mixed smelting is shown by the fact that an increase in the proportion of dense ores smelted from 50% to 75% has been known to result in an increase of 100 lb. in the carbon consumption per ton of pig.

Mr. **G. H. Johnson** (The Kettering Iron and Coal Co., Ltd.) : The broad indications arising out of the laboratory work detailed by the authors are particularly interesting as applied to home ironstone. The time/temperature curves plotted in Figs. 2, 3, and 5 of the paper emphasize how the presence of moisture retards the rate of temperature rise. In Fig. 2, for example, a sample of dried Oxfordshire ironstone reached a temperature of 700° C. in 6 min., yet a sample of undried Oxfordshire ironstone required 12 min. to reach the same temperature, the specimens in both cases being cylinders only 2¾ in. long by 1 in. in diameter. Similar results are plotted in curves *a* and *b* of Fig. 8, which give a comparison of the temperature rise of dried and undried Eaton ironstone at the blast-furnace rate of heating. It is safe to assume that the reduction in the rate of heating is greater in a blast-furnace, because the pieces charged are generally larger than those used for the tests. Thus when ironstone containing moisture is charged the rate of temperature rise will be retarded and the incidence of indirect reduction will be delayed. In consequence, reduction which would otherwise be indirect will not be completed until the ore reaches a level in the furnace at which solution loss occurs. In other words the presence of moisture will lessen the amount of indirect reduction and increase the direct reduction at the expense of fuel economy.

These experiments tend to confirm the need for the development of ore-drying equipment. If home ironstone were in the highest state of oxidation and dry, only the real ' dead fines ' would require some form of agglomeration by a process which resulted in a product with similar porosity and hence similar reducing characteristics to the bulk. I find no difficulty about distributing and dealing with dry ' coarse fines ' day by day.

Curve 3*c* of Fig. 8 shows the temperature at the centre of a cylinder of undried Northamptonshire ironstone approximately 3½ in. in diameter by 3½ in. long. In this case the centre of the lump reached only 490° C. after 2½ hours' heating, although the surface had reached 690° C. This marked difference was due first to the effect of moisture and then to the strongly endothermic reactions as decomposition of siderite, etc., proceeded. A temperature lag of this order must seriously lessen the amount of indirect reduction and suggests that the original practice of calcining many of our native ironstones was based on sound thermal and chemical principles. The tabulated data on page 212 of the paper, considered in conjunction with Fig. 23, brings out very graphically the difficulties of smelting mixed-ore burdens unless the various ores are selected so that they have similar porosity and hence similar reducing characteristics ; it is obviously impossible to design or operate ore-crushing plants to provide day by day the range of sizes suggested by the data presented.

These are considerations arising from the work reported in the paper, which was, of course, carried out in the laboratory. In an operating blast-furnace the temperature at varying radial distances from the centre is not uniform. The rate of stock descent at different radial distances is similarly variable, and so both the rate of heating and the time of contact of the ore with the ascending gases are diverse. Hence any conclusions drawn from this paper must be linked up in a working blast-furnace with the difficult problems of distribution, stock descent, and gas flow.

Dr. **Magnus Tigerschiöld** (Director of Research, Jernkontoret, Sweden) : In Sweden we have used magnetite ores for many centuries, and we learned in the early days the necessity of calcining them before use in the blast-furnace. I would like to ask Dr. Saunders if he has made any reduction tests of dense magnetite ores after they have been heated in an oxidizing atmosphere before reduction and compared them with dense magnetites in their normal state. In my opinion this treatment has an appreciable effect on the reducibility. We also found that when sintering fine magnetite concentrates it is essential to make the sinter highly oxidized. If one sinters at a too high temperature a slagged shiny surface is easily obtained, and the reducibility decreases quite appreciably. This is not only owing to the formation of fayalite but also, according to our experience, to the low degree of oxidation and a low porosity.

In Fig. 23 porosity is plotted against reducibility, and the authors draw a straight line in the graph. There are, however, discrepancies in that line, some of the points being quite far away from it. I think that is very natural and must be expected.

When measuring porosity the surface of the pores is not measured. If I may exaggerate a little, suppose there were only one pore in the middle of a lump of ore ; the porosity might amount to, say, 30%. With a million pores there would be a much bigger surface for reduction, and still the porosity might be 30%. The measurement of porosity by the present methods cannot give an appropriate answer.

Possibly the high oxidation has not so much effect in itself ; the type of porosity produced when making the highly oxidized sinter might be the main reason for the better reducibility. With higher oxidation there are very many fine pores, whilst with low oxidation there are a few big pores with shiny surfaces and perhaps also quite a lot of fayalite formation in the sinter.

The actual results achieved in Sweden by following these lines are clear from the work at Domnarfvet. Before starting the sintering plant there 15 years ago they had a coke consumption of more than 2000 lb. per short ton of pig iron. Now, using highly oxidized sinter and a somewhat richer ore, they have reached the world record of 1300 lb. of coke per short ton of pig iron.

* *Journal of the West of Scotland Iron and Steel Institute*, 1946–47, vol. 54, p. 13.

XUM

The burden, including the lime, contains 55% of iron ; the lime is crushed very finely and mixed with iron-ore concentrate before sintering.

Mr. **W. Banks** (Colvilles, Ltd.) : If the authors' figures for crushing sizes are accepted care must be taken not to hinder efficient reduction by upsetting the distribution. On a furnace operating with a high percentage of Swedish ore crushed to ½–1 in., together with larger-sized soft ores, it might be found that as the charge leaves the bell all the Swedish ore will be deposited at the furnace periphery and so travel down a relatively cool part of the furnace, whilst the soft ore will roll to the centre. This condition will be aggravated if the furnace is working with a **V** stockline and will lead to channelling, with consequent high top-gas temperatures and high dust losses. The laboratory experiments are based on an even temperature rise which may not be so inside the furnace.

The varying gas pressures or the gas velocity throughout the furnace must also be considered. From my own experience I would say that the pressure differential between the tuyeres and the stockline has some effect on reduction, having observed that very good gas ratios were obtained when the furnace was working sluggishly with occasional slips and checks, giving rise to high tuyere pressures and low top-gas pressures. It is often the case that very good gas ratios can be obtained if the sample is taken when the furnace is hanging. I would like to have the authors' opinion on the question of gas velocity.

Dr. **J. Taylor** (The Royal Technical College, Glasgow) : I wish to comment chiefly on the section on the penetration of reduction into lump ores. I think that, except for the point raised by Mr. Johnson, the effect of heat penetration has been very effectively disposed of in this paper. In the majority of cases heat penetration is not an important factor.

As far as reducibility is concerned there are much wider differences than for the penetration of heat. These are strikingly illustrated by the data tabulated on page 212, which are of the greatest interest to the study of the blast-furnace process because the reducibility of the burden is the major factor in thermal efficiency. Whilst I believe that the sizes given on page 212 indicate by and large the differences which exist between iron ores, the values given should be regarded with caution. For instance the proportion of indirect reduction for a given thermal efficiency is larger the leaner the ore, *i.e.*, a rich hematite ore does not require to be so reducible as a lean home ore, for the same efficiency. The lump sizes given on page 212 are therefore, in my view, too favourable to the lean home ores.

One feature of the experimental results which I found surprising was that the amount of reduction was comparatively small. The experimental procedure was designed to simulate operating conditions but it is clear that reduction must be more efficient in the blast-furnace than in the authors' experiments. The amount of oxygen remaining in the 3-in. Ouenza lump would imply a very high proportion of direct reduction, that is to say, very inefficient operation. This is probably connected with the surprisingly high oxygen content at the surface of the lumps. In many cases this was 1·1 atoms per atom of iron. The explanation may be in the much smaller gas velocity used in the laboratory experiments as compared with the blast-furnace, about 0·7 ft. per second as against 20 ft. per second, but it is not certain how this would affect the results. In the paper penetration has been considered solely as a function of the ore, but if gas velocity has been a limiting factor in the experiments it could affect the reduction of the different ores to a varying degree. The experimental difficulties are, of course, realized, but the possible effect of this disturbing factor ought to be borne in mind.

Concerning the relationship between porosity and penetration, Dr. Tigerschiöld made an important point in stressing the importance of pore size in addition to total porosity. The nature of the iron oxide can also be important. In experiments carried out some time ago on the reactions between powdered iron oxides and carbon monoxide I found the previous history of the iron oxide to be most important. For instance, Fe_3O_4 made by oxidation of iron, *i.e.*, millscale or the like, could be converted to FeO only after several hours' treatment at 750° C., whereas other samples of Fe_3O_4, obtained by reduction from Fe_2O_3, were quantitatively converted into Fe_3C in two or three minutes. I mention this to stress the point that I think the relationship between porosity and penetration of reduction can be pushed too far. It is another example of partial correlation, with which those interested in the blast-furnace are only too sadly familiar.

CORRESPONDENCE

Dr. **D. D. Howat** (The Royal Technical College, Glasgow) wrote : In Figs. 12, 17, 19, 20, 21, and 22, several of the curves showing the penetration of the reducing gases into the ore pieces may be divided into three sections of different slopes. The first and steepest part of the curve extends from the surface a small distance into the specimen, the value of the oxygen/iron ratio at the surface being 0·6/0·85. This is followed by a second and flatter part of the curve, the break between the first and second parts corresponding to an oxygen/iron ratio of 1·0/1·15. The final horizontal part has an oxygen/iron ratio corresponding to the unreduced oxide. Is it possible that the two sloping sections of the curves correspond to different regions of the iron–oxygen equilibrium diagram ? In that case the first section would correspond to the presence of two phases, namely, iron, saturated with oxygen, in equilibrium with wüstite solid solution. The limits of the wüstite solid solution—23–25·5% of oxygen—correspond to an atomic ratio of oxygen/iron of 1·03/1·14. The second section of the curve will correspond to the phases wüstite solid solution, magnetite, and up to unreduced ferric oxide.

It may be noted that the Sierra Leone ore (No. 2 in Fig. 12) does not behave in this way, the minimum oxygen/iron ratio at the surface of the ore piece being 1·15, which is just on the wüstite solid-solution range. Similarly the highly permeable home ores in Fig. 19 also give a minimum oxygen/iron ratio at the surface of 1·05/1·15. Can the authors offer any explanation of the apparent difficulty, at 940° C., of reducing the oxygen content of these ores to less than corresponds approximately to FeO ?

This question causes another difficulty in correlating the data tabulated on page 212, according to which there are four ores giving a penetration of 0·8 in. and over, namely, Sierra Leone, Konakry, Oxfordshire, and Frodingham siliceous. On the basis of these tests each of these ores would be crushed to approximately the same size limits. But when a mixture of these ores reaches the same level in the blast-furnace the oxygen/iron ratio in the Konakry ore would be 0·75, whilst that in the remaining three ores would be 1·05/1·15, that is, below this level there would be considerably more reduction to be done on the Sierra Leone, Oxfordshire, and Frodingham siliceous ores than on the Konakry. It may also be noted that the porosity of the Konakry ore (28·8%) is substantially lower than that of the others.

Is it possible that the extent of the reduction of ferric oxides is determined as much by the crystalline structure of the oxide or by the ability of oxygen atoms to diffuse through the lattice as by the penetration of reducing gases through the pores ?

AUTHORS' REPLY

Dr. **R. Wild** wrote in reply : As Mr. Towndrow has stated, the problem of smelting a mixture of ores of widely differing reducibilities cannot be solved simply by crushing the ores in such a manner that all would undergo the same degree of indirect reduction. It would seem that a dense magnetite, for example, may best be reduced either by making available sufficient hearth heat for direct reduction or by crushing and reconstituting, preferably under oxidizing conditions, to give material with a more open texture.

It is undoubtedly true, as Mr. Johnson pointed out, that drying and calcining home ores would considerably lessen the thermal load in the blast-furnace, with beneficial results, but it should be noted in this context that most home ores disintegrate readily as they descend, thus lessening the ill effects of temperature lag within the lump, and also that there is normally stack heat available for ore preparation.

We have not directly compared the permeability of raw and calcined magnetites but we would agree with Dr. Tigerschiöld that marked increase in reducibility would probably result from calcination. In regard to the limitation of porosity measurement it should be emphasized that in the method we used, *i.e.*, the S.K. porosity test, we endeavoured to differentiate between the large pores—which we call voids—and the small pores, only the latter being considered in the assessment of porosity. The figures quoted by Dr. Tigerschiöld give striking proof of the advantage to be gained by increasing the reducibility of the material to be smelted.

Whilst it is doubtful whether a size range of ½–5 in. would be appreciably wider than that normally encountered in a furnace burden, the point raised by Mr. Banks concerning segregation does focus attention once again on the necessity for controlled distribution and the manner in which apparently different problems are interrelated. In regard to the effect of gas velocity up the stack upon reduction, it would seem probable that lower velocities would lead to increased gas/solid contact times, with a consequent increased efficiency of gaseous reduction.

The optimum ore sizes quoted in the paper were deduced solely on the basis of indirect reduction, and thus in an overall consideration of the entire smelting process the effect of the anticipated amount of direct reduction must, as Dr. Taylor pointed out, also be taken into account. The overall extent of gaseous reduction is certainly less than that accomplished in the blast-furnace ; the lower gas velocity, which was imposed by the limitations of laboratory-scale work, may be partially responsible and also the fact that, in the blast-furnace, indirect as well as direct reduction may take place in the 900–1100° C. zone, which is, as Mr. Towndrow said, a region where a complete study of the reactions still remains to be carried out.

If the limitation of reduction imposed by a lower gas velocity differs with various ores it would seem that the more reducible ores would be most affected, thus tending to increase still further the marked disparity between the penetrabilities of porous and non-porous ores. There is little doubt that factors other than porosity influence the extent of ore reduction, as we have pointed out in considering the behaviour of various magnetites, but we consider that it has been established that ore porosity exerts the most important influence upon the penetration of reduction.

Dr. Howat's suggestion that the point at which the oxygen gradient into the lump changes with certain ores may be linked with the wüstite solid-solution region is very interesting, and should undoubtedly be given serious consideration if the state of the reduced annulus was being examined in greater detail. Such a study would also be necessary before accurate conclusions could be drawn concerning the oxygen content of the narrow surface layer. In regard to Dr. Howat's comparison of the relative states of reduction of Konakry and the other most permeable ores, it should be pointed out that (*a*) the figures quoted refer to the narrow surface zone only, the mean values within the reduced zone being approximately : Konakry 1·15 atoms of oxygen per atom of iron, other highly permeable ores 1·23 atoms of oxygen per atom of iron, and (*b*) whilst the porosity of Konakry is relatively low its effective permeability is considerably greater owing to the presence of cavities within the lump.

Joint Discussion on the Papers—

THE DISTRIBUTION OF TEMPERATURE IN INGOT MOULDS AND ITS RELATION TO INGOT STRUCTURE* *By I. M. Mackenzie and Andrée Donald*

INGOT HEAT CONSERVATION. TIME STUDIES FROM CASTING TO ROLLING† *By A. V. Brancker, J. Stringer, and L. H. W. Savage*

and INGOT HEAT CONSERVATION. MOULD AND INGOT SURFACE TEMPERATURE MEASUREMENTS‡ *By A. V. Brancker*

Mr. **I. M. Mackenzie** (Colvilles, Ltd.) presented the first paper.

Mr. **L. H. W. Savage** (British Iron and Steel Research Association) introduced the second paper, and also that by Dr. Brancker.

Mr. **N. H. Bacon** (Steel, Peech and Tozer) : The paper by Brancker, Stringer, and Savage deals with a subject which is particularly important in these times of high

* *Journal of The Iron and Steel Institute*, 1950, vol. 166, pp. 19–28.

† *Ibid.*, 1950, vol. 164, pp. 67–84.

‡ *Ibid.*, 1950, vol. 165, pp. 307–313.

fuel costs. The authors draw particular attention to the fact that although the steel at tapping contains 5 therms per ton more heat than is required for rolling, no less than 10–20 therms have to be supplied in the soaking pits. At Templeborough, where most of the ingots are charged hot, the fuel requirements are as follows :

Time in Soakers, hr.	Fuel Requirements, therms/ton
3	5½
6	12
9	19

Cold-charged ingots require 10 or more hours in the soakers and 20–25 therms per ton.

The authors' studies at three works have led them to the conclusion that a considerable reduction in track times is possible. The assumptions outlined on pages 70 and 71 of the paper, assumptions regarding which the authors say " observations suggest are readily attainable," represent achievements no doubt readily attainable on paper, but I doubt if any melting-shop or mill man will agree that they are readily attainable in practice. For example, Works *A* shows an efficiency of about 65%, compared with the possible performance envisaged by the authors. The efficiency achieved at Templeborough is also about 65%, despite the fact that the whole procedure from tapping to charging in the soakers is very closely watched, that is :

Tap to Charge in Soakers	Desired	Achieved
22½-in. sq. semi-closed-top ingots	2½ hr.	3¾ hr.
22½-in. sq. brick-top ingots	3 hr.	4 hr.

On page 71 of the paper the authors write : " These tables (Tables I and II) suggest that the order in which the ingots are taken is of potential importance," and it is suggested that 14 min. track time would be saved if the ingots were stripped in the same order in which they were teemed, instead of—owing to certain practical difficulties—in the reverse order. While everyone will agree, I think, that it is desirable to strip in the order teemed, there appears to be no sound reason why stripping in the reverse order should lengthen the period between tapping and charging into the soakers.

The problem of reducing track times is tied up with the bunching of the furnace taps, and the greater the number of furnaces involved or the larger their capacity the more difficult does this problem become. Naturally, the melting-shop manager is concerned to get his casts tapped as quickly as possible and the mill manager to get his ingots into the soakers as hot as possible, and there does sometimes seem to be a lack of adequate liaison between the two. Once the better spacing of furnace taps is achieved the track-time problem will be largely solved.

To turn to the paper by Dr. Brancker, it was well known, of course, that large temperature variations occurred in the moulds as a result of the teeming operations. This author has shown very clearly the magnitude of such variations and the desirability of greatly reduced stripping times. Most striking differences in temperature are to be observed, for example, between moulds stripped in 30 and 60 min., respectively :

	30 Min.	60 Min.
Approx. temperature of narrow sides	(1) 385° C. (2) 445° C.	(1) 530° C. (2) 600° C.
Approx. temperature of broad sides	(3) 465° C. (4) 580° C.	(3) 660° C. (4) 730° C.

This subject of stripping time is of the greatest importance from the point of view of both heat conservation and mould life. It has been demonstrated by many workers that mould life can be greatly increased—doubled in some cases—by quicker stripping, yet little appears to be done about it.

The paper by Mr. Mackenzie and Mrs. Donald is an excellent piece of work and the authors are to be congratulated on their beautiful micrographs. The authors' arguments, together with Fig. 23, seem to put a quite convincing case for their conclusion that the gap between ingot skin and mould wall is formed 2 min. after casting, but practical experience suggests that the gap is formed almost immediately the metal comes into contact with the mould wall, that is, under normal conditions of teeming practice and superheat. To give two examples in support of this conclusion : At the Ruhrstahl Henrichshütte plant in Hattingen single block ingots for wheel centres were being bottom cast in small-end-up 12-sided moulds 10⅞ in. across by 25 ft. long, and completely closed at the top end. The moulds filled without difficulty, the air escaping between the ingot skin and the mould wall as filling proceeded. About 25 years ago, when single block ingots were being made at Templeborough for wheel centres, an incident occurred which again supports the assumption of the almost instantaneous formation of an air gap, however small. The ingots were bottom cast in groups of eight into moulds about 20 in. dia. by 10 in. deep. On the first group the teemer was unable to shut off owing to the stopper rod having burnt in two, and almost simultaneously the electric power failed. The moulds filled and then started lifting, and ingots 3–4 ft. long were produced, the ingot skins alone supporting the liquid interiors. It seems unlikely that the moulds would have lifted in such an easy manner had the ingot skins been in actual contact with the mould walls.

Mr. **A. Robinson** (Appleby-Frodingham Steel Company) : The importance of ingot heat in saving heating costs at the soaking pits is self-evident, and the constant flow of properly heated ingots when required at the slabbing or cogging mill is necessary in order to keep production up to its top limit. These are questions that cause many headaches to mill managers. For a metal, a steel ingot seems curiously slow in heating to an approximate even temperature throughout. A cold or half-cold ingot can be flashed up on the outside very quickly, but such ingots cause considerable trouble through cold centres.

Some years ago experiments were made at Appleby-Frodingham to compare the heating and cooling of the outside and inside of the ingot. Ten-ton ingots were used as a standard, and cooling and heating curves were obtained by embedding a blank-ended steel tube down the centre of the ingot immediately after casting, this tube being prevented from melting by blowing compressed air down it for some minutes. Test ingots were sent to the strippers and soakers as usual, some were allowed to cool for hours in the mould, some were stripped and put into Gjers pits, some went normally into the soakers, and some were allowed to go cold and reheated. The top of the tube was covered to prevent undue oxidation. The temperatures of the inside and outside of the ingots were measured normally by an optical pyrometer, which was checked repeatedly by a thermocouple in or on the ingot. Typical results were as follows :

(1) Ingot Allowed to Stay in Mould. Internal Temperatures Only

Hr.	Min.	Temperature, ° C.
0	45*	...
1	15	1450
2	0	1390
3	0	1200
4	0	1030
4	30	960

* End of teeming and tube cooling

(2) Ingot Stripped and put into Gjers Pit

Time After Teeming, Hr.	Min.	Temperature, ° C. External	Internal
1	0*	1090	...
1	40†	840	1400
3	0	720	1190
5	0	750	1020
7	0	770	950
10	0	730	840
13	0	700	780
15	0	...	750
23	0	...	730

* Stripped
† Into Gjers

(3) Cold Ingot Charged to Soaker

Time After Charging Hr.	Min.	Temperature, ° C. External	Internal
1	30	910	300
2	25	1020	520
4	45	1160	730
7	0	1280	950
9	30*	1350	1190

* A further 3 hr. did not bring the internal temperature nearer than 100° C. to the external

(4) Hot Ingots Charged to Soakers

The outside temperature of the ingot rose and the inside temperature fell until the ingot was at even heat inside and outside, and at a rolling temperature in somewhat less time than the time elapsed between tapping the furnace and charging the ingot to the soakers, to the extent of ½–1 hr., depending on this elapsed time.

Out of these tests we evolved a method of charging that gives us good service. Ingots are cast from our large tilting furnaces in batches of 225–300 tons in three or four ladles or casts, and can cause considerable difficulties at our rolling mills by floods and famines unless care is taken. Ingots are cast in the order received by the mill. Ten-ton ordinary ingots are normally stripped 1½ hr. after the furnace is tapped, but no ingot is charged in less than 2 hr., to allow the interior to set, the ingot standing on the car. Ingots are put into the soakers as required, and any ingots not wanted within another ½ hr. are put into the Gjers pits or, if in excess of requirements, into stock. Cold ingots are, if possible, heated in a small preheater furnace to 900° C. before charging, or are charged into the soakers if the call is too great for the preheater ; only soft ingots are charged direct, except when getting ready for the mill on Sunday night, when a soaker can be cooled down previous to charging. Ten-ton ingots, which are charged 2 hr. after tapping, take 1½ hr. to heat, and for every 1 hr. delay 1 hr. is added to the heating time ; ingots which have been in the Gjers pits require ½ hr. extra heating time for every 1 hr. in the pits. Cold 10-ton ingots require 10–12 hr. to heat satisfactorily, and preheater ingots approximately half this time. There are similar specified times for 7-ton and 15-ton ingots. These three ingots sizes cover practically all our requirements.

This sounds complicated, and was extremely difficult to work properly until we devised a planning board which shows at a glance the position likely for at least two shifts ahead. This is at least 90% efficient in preventing delays owing to lack of steel at the mill, or overtiming in the soakers. The board covers 24 hr., and is divided vertically into ½-hr. sections and horizontally into spaces for furnace casting times, Gjers, preheater, and four soakers. Along the top is a series of clips into which the melting-shop prophecy of the furnace casting times is put at the prophesied time.

A preliminary estimate for the next tap from each furnace is given as soon as the furnace has been tapped and examined. This is modified or confirmed as soon as the furnace is fully charged, and again when the slag is run off and the bath sample analysed ; this latter estimate is usually accurate to ½ hr., and any expected delay on this is immediately notified to the mill. On tapping, the quality, number, and size of ingots from each ladle or cast are given to the mill and the order of stripping is agreed, any specially urgent cast being given priority.

While the mill is waiting for the ingots a ticket is made out for each ingot, and on receipt of the ingots the cards are put into the appropriate pocket (which shows the position in the Gjers pits or soakers) as the ingots are charged, in the case of the Gjers pits at the charging time and in the case of the soakers at the estimated drawing time. The cards recording cold ingots charged into the preheater are placed in a pocket showing the time when the ingots will be ready for charging to the soakers. With each ticket is placed a coloured transparency to show whether the ingot is for the 10-ft. or the 7-ft. mill, or for sale as slabs or blooms, or for stock slabs.

The board thus gives everyone interested a full view of the present and future position, and the likelihood of shortages, etc., which can be tackled in time by charging cold ingots direct if necessary or charging cold slabs into the plate-mill reheaters. The mill shift supervisor keeps in close touch with this board and is able to modify the charging in good time if the mills are going faster or slower than was expected, and can arrange to stock slabs or take out of stock to prevent delays at the plate mills. The running of this plan board has proved very simple and greatly to the mills' and melting shop's advantage, and has removed the cause of friction that often develops between these departments over steel supplies.

Mr. **H. H. Burton** (English Steel Corporation, Ltd.) : My remarks concern solely the paper by Mackenzie and Donald. I feel that the subject dealt with is one which needs still more study in spite of the researches which have been published already. In the first place I am rather surprised to find that in their bibliography the authors do not mention specifically the work of Lightfoot in the very early days and that of Russell in more recent times. Both of these contributions would have repaid the authors' study.

In connection with the section headed " Mechanism of Ingot Cracking," the authors say, in the first place, that " large cracks obvious before rolling are invariably transverse." I am sorry to contradict them, but our experience is that that statement is not true. Some very large longitudinal cracks can occur, not only on the corners but also down the panels of ingots cast under certain conditions which are being investigated by my Company at the present time.

The authors suggest that large transverse cracks are caused by the ingot " hanging in the mould." I know that this explanation is very widely held, but I doubt whether it is correct in many cases and think rather that most severe transverse cracks are caused by the alternate surging and lagging of the steel in contact with the mould during casting. In this way quite appreciable notches are formed in the ingot surface, though often the skin has to be examined very critically in order to find the discontinuity. When such notches exist it is obvious that any appreciable tension in the skin of the ingot will bring about an extension of the notch to form a crack. If hanging in the mould were the only explanation it is difficult to understand why, in the case of a crack formed

very shortly after solidification, more bleeding of the molten metal does not take place from the centre, in a manner somewhat analogous to that experienced in the continuous casting experiments carried out by the British Iron and Steel Research Association.

In regard to the question of what happens when the gap forms, my Company has done some work in which the gap between the ingot skin and the mould wall was filled with molten lead. Somewhat surprisingly, the increase in heat transfer between ingot and mould brought about in this way appeared to exercise no influence upon the depth of the columnar crystals, though the outer wall of the ingot presented, on etching, what might be termed a 'heat-treated' appearance, even to a depth below the length of the columnar crystals. There is little doubt that this phenomenon resulted from the envelope of the ingot being cooled below the transformation temperature and subsequently reheated from the interior during the later stages of cooling in the mould. That the introduction of the lead did increase the heat transfer was clearly shown by the fact that the portion of the mould in which the gap was filled with lead became red-hot very rapidly, whilst the portion above it, which was not so filled, never reached more than a very low red temperature, not visible in daylight. The experiments just described have definite bearing upon the question of how long the ingot skin remains in contact with the mould wall, since our experience was that lead could be admitted into the space between ingot and mould immediately any solidification had taken place. The molten lead actually followed up the pouring of the ingot within a few inches during the whole of the casting process.

Mr. **B. M. Tigerschiöld** (Degerfors Järnverks A.B., Sweden) : I just want to make a few remarks on the question of *when* a gap is formed between the ingot and the ingot mould. Mr. Bacon has told us he thinks this occurs almost instantly and I quite agree with him. At our works we make about 40,000 tons of ingots a year, bottom-poured in 'blind' moulds, *i.e.*, moulds entirely closed at the top end. As there is very little, if any, delay in pouring rate as compared with open-topped moulds, a gap is bound to be formed almost immediately as the pouring proceeds, otherwise the air in the mould could not escape. I measured the pressure inside such a mould during filling and it was found to be very low, not exceeding 1½ in. W.G., which also proves that the gap is formed very quickly.

Finally, I want to tell of a curious thing which happened at our plant some time ago. On one occasion, when the tapping of a set of blind slab moulds was almost finished, one of the moulds suddenly cracked from top to bottom, the two halves falling apart. As we did not want to make scrap of all the ingots in the set, we continued the pouring as if nothing had occurred. The ingot without a mould then grew thicker and thicker, until at last it looked just like a cushion.

CORRESPONDENCE

Dr. **D. Binnie** (Lancashire Steel Corporation, Ltd.) wrote : In the work reported by Mackenzie and Donald reference is made to my paper on a shell-steel ingot,* in the course of which I discussed a type of banding seen by sulphur printing by hot acid etch, but not by cold copper etches. Experience has also shown that this banding, called 'zoning,' does not appear in carbon steels until the carbon amounts to at least 0·30%, so I doubt very much if the authors could have noticed it in their ingot. Zoning is quite unaffected by rates of teeming, the steelmaking process, top or bottom teeming, hot or cold casts, and many other variables ; it does not appear in steel cast in refractory-lined moulds, and I am certain that if the authors teemed an ingot (a small one would suffice) into a composite mould—one half chill the other half refractory—they would obtain interesting data of a theoretical nature of value in attacking the problem of banding generally.

Many theories have been proposed to explain the cause of zoning. They mostly turn on turbulence in one way or another, but I doubt very much if that is the reason ; for example, two ingots, one of which was teemed through a 1⅛-in. nozzle and the other through a 1¾-in. nozzle, showed precisely the same development and extent of zoning. Zoning and copper-etch banding are not the same, but there is some parallelism between them.

The authors have considered at some length the effect of superheat on the air gap between the mould wall and the ingot, and attach importance to this relationship. I am in agreement that the early formation and extent of the air gap are factors in the development of banding and zoning. Banding is present most of all where there can be no air gap, *i.e.*, the bottom end of the ingot. The head of liquid metal pressing down on the steel, freezing under chilled conditions striates the surface causing banding and zoning. I do not think turbulence comes into it at all.

Monsieur **P. Leroy** (Institut de Recherches de la Sidérurgie, France) wrote : It is very interesting to know that Mackenzie and Donald have succeeded in calculating the rate of heat transfer from ingot to mould and the ingot-skin thickness relating to the solidification time in a 3-ton fully killed ingot. Results would be different on rimming ingots, as gas evolution would modify the heat exchange, but, nevertheless, we think that a comparison between rimming and killed ingot solidification could be instructive. In France we are going to study the rimming ingot solidification in a basic Bessemer steelplant ; we shall not attempt to measure the distribution of temperature of ingot moulds, but the temperature of liquid steel in ingot moulds in function of time. The ingots will then be upset at different moments of their solidification and it should be possible to observe the skin thickness, the rate of solidification, and the ingot structure.

Mr. **W. H. Glaisher** (British Iron and Steel Research Association) wrote : In the paper by Mackenzie and Donald it is shown that the temperature of the ingot exterior falls very rapidly after teeming. From Fig. 23 it appears that, taking as zero time the instant at which the liquid steel reaches the point being considered, the ingot surface has cooled to 1400° C. in about 1 min., to 1200° C. in about 1½ min., and to 800° C. in about 2 min. Subsequently the temperature of the surface rises, reaching a maximum of approximately 1150° C. Cracking must occur before the skin has developed any appreciable ductility. Hall* has shown that in some steels ductility is developed at temperatures as high as 1400° C., and in work on hot-tearing Middleton and Protheroe† found that in 1¼-in. dia. sand-cast bars tearing occurred at about 1400° C. or not at all. It would thus appear that cracking of ingot skins occurs

* *Journal of The Iron and Steel Institute*, 1944, No. I, p. 353P.

* *The Iron and Steel Institute*, 1936, *Special Report No.* 15, pp. 65–93.

† *Journal of The Iron and Steel Institute*, 1951, vol. 168, pp. 384–399.

at a time of the order of 1 min. or less after the steel has reached the point in the ingot being considered.

It is suggested on page 27 of the paper that the cracking is caused by tensional stresses set up in the plane of the skin, owing to it being in contact with the rough wall of the mould which is expanding. The expansion of the mould wall during the first minute is extremely small, probably not more than 0·05%, but a larger tensional stress will be set up owing to the fact that the cooling ingot skin is prevented from contracting. Taking the coefficient of linear expansion of the steel to be $0{\cdot}20 \times 10^{-4}$ in./in./° C., the contraction in cooling from 1520° C. to 1400° C. would normally be 0·24%, so that the surface of the ingot is in effect strained by a total of about 0·3% when it has cooled to 1400° C. Thus the steel is cracked owing to its inability to withstand a very small degree of straining. This consideration underlines the importance of further study of the mode of solidification of steels and of the constitution of the interdendritic material, which undoubtedly is the weak link, *at the time and temperature at which the cracking occurs*. The main purpose of this contribution to the discussion is to stress this point. Arising from the same point, since the major stress in the ingot skin in the first minute or two is caused by the fact that it is prevented from contracting, rather than that it is stretched by contact with the expanding mould wall, it seems likely that the thickness of the mould wall will have little or no influence on the incidence of cracking.

AUTHORS' REPLIES

Mr. **I. M. Mackenzie** wrote in reply : The remarks of Mr. Bacon and Mr. Tigerschiöld, regarding the nature of the contact between the ingot skin and the mould wall immediately after teeming, are of great interest. These observations confirm that true metallic contact between the liquid steel and the cast iron never exists, and there is always a ' gap ' between ingot and mould, although initially this is too narrow to affect heat transfer appreciably.

The authors would assure Mr. Burton that they have not overlooked the excellent work on the theoretical side, which was done by Lightfoot, Russell, and others. However, no attempt was made to include a bibliography in the paper. The authors merely listed those publications to which they found it necessary to refer. While the mathematical work on heat transfer is of great interest it is not relevant to the consideration of conditions immediately following the teeming of the ingot.

The authors regret that they suggested that major longitudinal cracks are not found in ingots. It appears that under the wide variety of conditions that exist in different steelworks all types of cracking are possible. It is not suggested that major transverse cracks are *caused* by the ingot hanging in the mould, but that pre-existing cracks are enlarged by hanging. From the evidence obtained in this investigation it is suggested that the small cracks are formed in the skin while it is very thin and hot and while it is being stretched by irregular contact with the rough mould wall. Under other circumstances, surging of the liquid steel during teeming may cause lines of weakness, which rupture when the ingot skin is subsequently stretched. Mr. Burton's experiments on lead seem to confirm that the columnar zone is formed very rapidly after teeming and before an appreciable gap is opened up between the ingot and the mould. This would explain why the introduction of lead made such a small difference to the structure.

It is possible that the authors are mistaken in using Dr. Binnie's term " zoning " to describe the light bands on the sulphur print of their ingot, since he asserts that " zoning " cannot occur in this quality of steel. But it is not clear in what respect the two phenomena differ.

The results of M. Leroy's experiment will be awaited with interest. It seems likely that, since the rate of increase of the thickness of the ingot skin depends principally on the rate of abstraction of heat, solidification should proceed at approximately the same rate for rimmed and killed ingots.

The authors doubt if their experimental data are sufficiently accurate to permit deductions of the type made by Mr. Glaisher for determining the time at which cracking of the ingot occurs. Since cracks may be initiated at either the interior or the exterior of the skin, the authors do not agree that the fact that the steel has its minimum ductility above 1400° C. can be used as evidence that cracking occurs within one minute after teeming, or that it results from very small strains.

Mr. **L. H. W. Savage** wrote in reply : Referring to Mr. Bacon's remarks, we agree that track times cannot always be maintained at the theoretical minima, and in our hypothetical operation we took a working minimum appreciably longer than some actually obtained (*see* p. 80). Because of bunching of furnaces and the assumed limitations on the use of the casting-bay and soaking-pit cranes, etc., it was possible to charge only 68% and 62% respectively of the casts from the two melting shops, within half an hour of this minimum, and the figure quoted by Mr. Bacon for Templeborough suggests that this proportion is reasonable.

The effect on the track time of the order of stripping is shown in Fig. 3 (p. 71). This assumes that an empirical minimum time from teem to strip is the same for the first as for the last ingot of the cast, which, in the present state of knowledge, is quite reasonable, as the change in temperature in the ladle during teeming is less than the variation in tapping temperature between different casts.

The figures given by Mr. Robinson of the temperature of ingots at various stages will be of use both to ourselves and to industry. The work described in Dr. Brancker's paper has now been extended to measurements of temperature through the mould walls, enabling the heat loss from the steel to be measured accurately and a first approximation to be made of the temperatures in the steel ; Mr. Robinson's figures provide a valuable basis for assessing the validity of these approximate methods. It is of particular interest to note that the heating times can be less than the track time from tapping to charging, for by reducing heating times the availability of the pits is increased, making it possible to charge subsequent casts at an earlier moment than would otherwise have been the case, and reducing average track times, heating times, and fuel consumption still further.

AUTUMN GENERAL MEETING, 1950

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 15th and 16th November, 1950, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. In the absence, owing to indisposition, of the President, Mr. J. R. MENZIES-WILSON, the chair was taken on the Wednesday and Thursday mornings by Dr. C. H. DESCH, F.R.S., Past President, and on the Wednesday afternoon by Mr. JAMES MITCHELL, C.B.E., Honorary Treasurer.

Sessions were held from 10.0 A.M. to 1.15 P.M. and from 2.30 P.M. to 4.45 P.M. on the Wednesday, and from 10 A.M. to 1.0 P.M. on the Thursday, a buffet luncheon being held in the Library of the Institute on the Wednesday.

The Report of the Meeting was published in the September issue of the *Journal* (vol. 169, p. 2).

Joint Discussion on the Papers—

THE THERMODYNAMIC BACKGROUND OF IRON AND STEEL MAKING PROCESSES. II—DEOXIDATION*

By F. D. Richardson

and STUDIES IN THE DEOXIDATION OF IRON: DEOXIDATION BY ALUMINIUM†

By H. A. Sloman and E. Ll. Evans.

Dr. **F. D. Richardson** (British Iron and Steel Research Association) presented the first paper, and Mr. **E. Ll. Evans** (National Physical Laboratory) the second.

Sir **Charles Goodeve** (British Iron and Steel Research Association): Dr. Richardson gives an excellent picture of the mutual action of a deoxidizer and dissolved oxygen in lowering each other's activity, in terms of a 'cluster' or a higher-than-normal probability of finding a deoxidizer atom in the layer of atoms surrounding each oxygen atom. This picture is not inconsistent with the statement sometimes made that aluminium or chromium, etc., oxides are slightly soluble in liquid iron, provided that we abandon the idea of a compound of a composition given by the chemical formula of the pure substance, persisting in the solution.

Sloman and Evans have dealt in more detail with an extremely important side of the whole problem, the products formed in deoxidation. The object in deoxidation is to cleanse the metal, and this can be achieved only by producing something which will come out of the liquid quickly, despite the stirring action which always goes on owing to thermal convection or to electrical induction, when present.

In recent years we have learned a great deal about the kinetics of nucleation and crystal growth. Do we understand enough about that in the particular cases considered here? Have we sufficient information to calculate the actual rate of rise in the liquid steel of the particles of, say, FeO with the spinel central core shown so excellently in the photographs in the paper? Since these particles are nearly spherical, their rate of rise should be calculable. Alumina has a tendency to form long-chain particles or crystals forming a spongy network, and it is therefore not surprising that similar structures have been found in some of the ingots referred to in this paper. I think that they must be bad structures from the point of view of cleansing, because their density must be almost that of the liquid iron and their settling rate towards the surface must be extremely small. It looks as though we have here a practical target, to get rid of these cluster formations and make them into proper crystals which will separate out.

Dr. Richardson referred to metastability and illustrated it in the case of the chromic oxide. Can we in fact get metastable systems of that type, or of the type that Hilty and Crafts‡ have supposed in order to explain their results, to exist at the high temperatures prevailing in liquid steel? Unless we find an answer we are always liable to use metastability as an escape to explain something which may be due to experimental error or to other disturbing factors.

Dr. **O. Kubaschewski** (National Physical Laboratory): Before going into the details of Dr. Richardson's paper, there is a general point which must be made quite clear. A mass-action constant of a slag/metal system can be calculated from the activities of the elements dissolved in the metal, iron for instance, at concentrations of approximately 1 wt.-%, and the free energy of formation of the slag. This will be a true equilibrium constant so long as three conditions are fulfilled. These are that (i) the fundamental data involved are accurately known, (ii) the mutual interaction of the dissolved substances is known quantitatively, and (iii) Henry's law is strictly valid for the dissolved elements between 0 and 1% by weight. I shall deal with these conditions in turn.

In regard to the first we are now, after an effort of almost 100 years, in possession of quite reliable data for many oxides and other metal compounds. Professor W. A. Roth, who died a few months ago, spent a lifetime on accurate determinations of heats of formation. Very little is being done in Europe at present to continue this work, but activity is fortunately increasing rapidly in the U.S.A. More work will have to be devoted to the thermochemistry of double oxides and other slag com-

* *Journal of The Iron and Steel Institute*, 1950, vol. 166, Oct., pp. 137–146.

† *Journal of The Iron and Steel Institute*, 1950, vol. 165, May, pp. 81–90.

‡ *Journal of Metals*, 1950, vol. 188, pp. 414, 425.

pounds. Data on metallic solutions are also very scarce. Most of the information on iron alloys comes from the laboratories of Professor Chipman and Professor Oelsen, but far more data are required.

Numerical information on the change of activity of oxygen, for instance, by alloying elements in iron is also inadequate at present. Dr. Richardson has quoted some results obtained by Chipman and has estimated a few more values. He has further compared the factor by which the activity coefficient is lowered by the additions with the difference between the heat of formation of ferrous oxide and those of the oxides of the added elements. The proportionality observed is to be expected and, I think, will be very useful as an empirical means of estimating the effect until the quantitative relationship governing the lowering of the activity coefficient is elaborated. The empirical relationship will generally be sufficiently accurate for calculations. I suggest that the lowering factor may be related to atomic, not to weight, percentages. In Richardson's Table I this would not alter the sequence of the alloying elements, except that carbon would be pushed almost to the top, where it belongs according to the difference in heats of formation. For purposes of comparison the oxides should all be considered in the same state of aggregation. This does not apply to carbon oxides in Table I.

If accurate thermochemical data are available and the mutual effect on activities is taken into consideration the application of calculation to actual equilibria depends on the validity of Henry's law, which is generally assumed to hold up to 1 wt.-%. Fortunately, this is approximately correct for ferrous oxide in liquid iron. As Dr. Richardson has pointed out, we may also expect some elements with a close resemblance to iron—such as manganese, nickel, vanadium, cobalt, and chromium—to form regular, if not ideal, solutions in iron. In the case of vanadium Dr. Richardson is not satisfied with the calculation of equilibrium constants and attributes the disagreement to errors in the free energy of V_2O_3. In the discussion of Richardson and Jeffes' earlier paper, I suggested* an improvement in their formula for V_2O_3, yielding a free energy of formation of − 194,000 cal. in place of − 207,000 cal. at 1600° C. The free-energy relationships in the system vanadium–oxygen have been worked out in more detail† and the free-energy value $\Delta G = 293{,}000 - 56{\cdot}15T$ is now proposed for the reaction $V_2O_{3(solid)} = 2V_{(solid)} + 1\frac{1}{2}O_2$.

The difference between Richardson's and our results then becomes equal to 9500 cal. per g.-atom of vanadium, and this increases the activity coefficient derived by Richardson by one power of ten. This brings it, of course, into good agreement with the value he expected to get.

A correction may also be suggested for boron in iron, since a redetermination of the heat of formation of B_2O_3 has been carried out at Farnborough‡ which gave a result entirely different from that of Todd and Miller. According to the redetermination the numerical value of ΔH_{298} is now 40 kg.cal. lower. This result was also mentioned in the discussion of Richardson and Jeffes' paper on oxides. A difference of 20,000 cal. for 1 g.-atom of boron corresponds to more than two logarithmic units, implying an activity coefficient of boron in iron somewhat higher than 0·1. This value is more probable than $\gamma_O = 0{\cdot}001$ suggested by Richardson, and would tend to confirm the new heat of formation of B_2O_3.

It is doubtful whether such calculations can be applied to solutions of aluminium and titanium in iron without further corrections, as the validity of Henry's law up to concentrations of 1 wt.-% may be questioned. The activity of an element i in solution can be represented by a free-energy equation of the form :

$$\Delta\bar{G}_i = A + BT\log N_i + CT,$$

where A, B, and C are constants, and N_i is the atomic fraction of the solute. A represents the partial molar heat of solution, C the entropy change owing to changes in state of aggregation, the condensation of oxygen into the liquid for instance. B depends on the entropy of solution and should be 4·575 if Henry's law is applicable. A numerical equation of this type can be derived for the solution of oxygen in iron from Chipman's measurements, and :

$$\Delta\bar{G}_{O_2} = - 55{,}860 + 9{\cdot}15T\log N_{(O)} + 12{\cdot}16T$$

is obtained. The value of $B = 4{\cdot}75$ for *one* oxygen atom confirms the applicability of Henry's law. It is useful to express activities generally in the form of such free-energy equations.

The dependence of the activity of aluminium on its concentration in iron has not been determined. By combining the partial heat of solution (quoted in Sloman and Evans' paper) with Chipman's free energy of solution (quoted in Richardson's paper) it would appear that the equation for the solution of aluminium should have approximately the following form :

$$\Delta\bar{G}_{Al} = - 26{,}000 + 1{\cdot}2T\log N_{Al},$$

suggesting a value of B much lower than 4·57.* If this is so the activity of aluminium in liquid iron should be calculated for the average of the concentration range in which measurements are made (and then, of course, related to 1%). This calculation is simple and shows that at an average concentration of 0·1% the calculated equilibrium constant must be multiplied by a factor c of 5. Thus the gap between calculation and observation queried by Richardson and ascribed to a rather large effect of aluminium on $\gamma_{(O)}$ becomes smaller ; the factor decreases from 10 to 6, which is more probable according to Richardson.

In regard to titanium in iron, Dr. Richardson has assumed equilibrium with titanium dioxide. An earlier estimation† of the heat of formation of TiO would suggest that it was this substance which should determine the equilibrium, but I have now to modify this earlier figure. Our earlier value was based on a communication by Chrétien and Wyss‡ that TiO_2 is reduced by magnesium not further than to TiO. Meanwhile we have at the National Physical Laboratory repeated the experiment of Chrétien and Wyss, with a result that suggests that the heat of formation of TiO is not far above 125,000 cal; $-\Delta H_{298}(TiO) = 129{,}000 \pm 6000$ may be given as the best estimate. This takes into account that the activity coefficient of titanium in iron, calculated by Richardson from the TiO_2 equilibrium, is in good agreement with a value $\gamma_{(Ti)} = 0{\cdot}12$ which we have estimated in connection with other work.

It follows therefore that most of the queried results obtained by Dr. Richardson in his paper are explained away in the light of further information and considerations.

* *Journal of The Iron and Steel Institute*, 1949, vol. 163, p. 150.

† N. P. Allen, O. Kubaschewski, and O. von Goldbeck (paper read at the 97th Meeting of the Electrochemical Society, Cleveland, 19th April, 1950), *Journal of the Electrochemical Society* (in the press).

‡ W. Eggersgluess, A. G. Monroe, and W. F. Parker, *Transactions of the Faraday Society*, 1949, vol. 45, p. 661.

* This value of 4·57 must, of course, be approached and finally reached at very low concentrations of aluminium.

† *Journal of The Iron and Steel Institute*, 1949, vol. 163, p. 150.

‡ A. Chrétien and R. Wyss, *Comptes Rendus*, 1947, vol. 224, p. 1647.

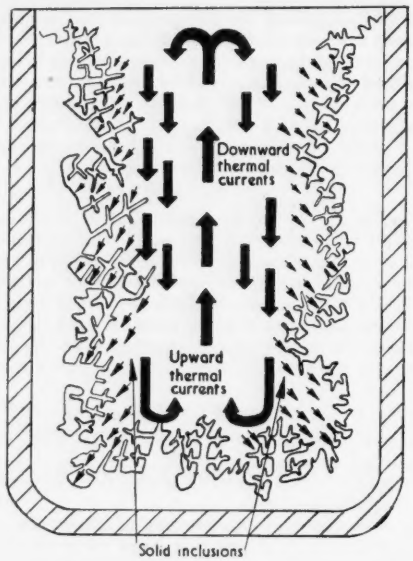
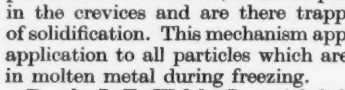


Fig. A—Suggested mechanism of movement of solid inclusions in crucible melting, resulting in deposition of the inclusions into the interstices of growing dendrites

Dr. **R. V. Riley** (Staveley Iron and Chemical Co., Ltd.) : My remarks will be confined entirely to the paper by Sloman and Evans. The most important possible criticism, to my mind, is connected with the melting of the steel in an alumina crucible. Are the authors quite satisfied that there is no solution of aluminium from the alumina crucible ? The work of Hilty and Crafts would appear to suggest that the equilibrium is never attained because aluminium is reduced from the crucible and continues to dissolve in the steel. I would suggest that, although this may appear to be a criticism of the present paper, there is another explanation of the presence of alumina particles in the metal near the crucible walls. In some work with which I have been connected, using another metal—cast iron, we have found that inclusions have a habit of being moved by thermal currents to the sides of the crucible.

I suggest that the way in which this is done is as represented in Fig. A. The thermal currents presumably carry the bulk of the inclusions up the centre of the melt and down the walls during the period previous to the solidification of the steel. One can imagine that the dendrites are forming the usual tree-like growth and that there is swirling past this solidifying surface, as it were, a dust storm of alumina particles. As the storm passes over the surface, alumina particles are deposited in the crevices and are there trapped by the progress of solidification. This mechanism appears to have general application to all particles which are solid or semi-solid in molten metal during freezing.

Dr. **A. J. E. Welch** (Imperial College, London) : Dr. Richardson referred to the possibility of oxygen being surrounded by perhaps six iron atoms in the melt, in the manner shown below,



and side by side with this is the possibility of an atom of an alloying element such as silicon being similarly surrounded by six, or some appropriate number of iron atoms. There has often been a tendency to regard the behaviour of reactions in such solutions in terms of certain lower oxides, in this case, for example, SiO. That is a thermodynamic interpretation, and since thermodynamics from its very nature is not capable of giving information on the structure of the systems concerned it is a permissible thermodynamic approach. In actual fact, however, the energy of the system is reduced by the association of a silicon and an oxygen atom. If the two were functioning independently these two sections of the solution could migrate independently throughout the mass, but, on account of the reduction of energy which takes place on association of silicon and oxygen, there will be a definite preference for silicon to associate itself with oxygen in its own environment.

A similar explanation must apply to the reduction of the activity coefficient of a dissolved element in the iron melt. If we take the case of, for example, silicon, the fact that the silicon activity coefficient is reduced in the melt (*i.e.*, the activity is not equivalent to the concentration) must be due to a definite reduction of energy when the silicon atom associates itself with an environment of iron atoms. To put it crudely, it is harder to dig the silicon atom out of its environment of iron atoms than to take it from a silicon lattice.

My point is referred to by Dr. Richardson when he mentions that the behaviour of nickel, for example, is approximately ideal, because of the similarity between nickel and iron, but he also suggests that the behaviour of metals such as titanium is not expected to be ideal because of the formation of intermetallic compounds. What correlation may we expect between the formation of intermetallic compounds in the solid state and the activity-coefficient behaviour of the elements concerned in liquid–metal solutions ?

A good deal of harm has been done in the case of slag systems in the past by assuming that the behaviour of a liquid slag can be interpreted in terms of the constitution of its solidification products. Is there a similar danger in the case of metal solutions of deducing that, because on solidification certain intermetallic compounds separate, the activity coefficient is reduced to a certain extent in the liquid solution ?

Mr. **W. A. Smith** (Stewarts and Lloyds, Ltd.) : From the two papers presented this morning it is fairly obvious that there is a good deal of disagreement over the equilibrium conditions of aluminium with oxygen in molten iron, and the purpose of my contribution is to submit data collected on a steelplant during steel production, which it is hoped will help in solving this problem.

The work was started immediately members of the Gases and Non-Metallics Sub-Committee had shown* that it was possible, by using the nephelometric method, measuring the oxygen as alumina, to obtain an oxygen figure during steelmaking in about 20 min. from drawing the sample. It appeared that this provided an opportunity of exercising a degree of control over deoxidation processes similar to that at present exercised over the refining reactions in the open-hearth furnace. Sampling from the bath itself proved a relatively straightforward matter, using the bomb-type sample containing aluminium for instantaneous killing. The results were consistent and agreed with vacuum-fusion checks within $\pm$ 0·003% of oxygen.

In following the matter through, however, to assess the results of our deoxidation practice, matters became a little more complicated, because during deoxidation, mainly in the ladle, additions are made of ferromanganese, ferrosilicon, and aluminium. The metal rising in the

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, pp. 388–415.

mould therefore already contains alumina from the ladle addition of aluminium, and so two bomb samples were taken simultaneously, one containing no aluminium and one with aluminium. At the same time the temperature was measured by the quick-immersion couple, and was found to lie between 1510° and 1530° C. The alumina in the two samples was measured by the nephelometric method and the difference was shown, by residue analysis of a proportion of the samples by the chlorine method, to be equivalent to the oxygen present in the steel as FeO, MnO, and SiO_2. This is directly in line with the work of the Gases and Non-Metallics Sub-Committee, to which reference has been made.

For several types of steel, all containing 0·10–0·25% of silicon, the difference in oxygen content of the two samples was plotted against the aluminium in solution in the steel, and the results are shown in Fig. B.

Bearing in mind that the analytical errors are of the order of ± 0·003% at these low concentrations for both oxygen and aluminium, we suggest that the data offer reasonably good confirmation that the Wentrup and Hieber curve represents fairly accurately the conditions during practical steelmaking. For comparison, Fig. B includes results based on the fundamental thermodynamic work by Chipman,* the more recent contribution by Sloman and Evans,† and the latest American work submitted by Hilty and Crafts ;‡ these have all been brought to 1540° C. for ease of comparison with the graph (Fig. 7*b*) given in Dr. Richardson's paper.

We should like to make two points. First, the apparent discrepancy between the graphs based on fundamental data and those of a more empirical nature that give a much higher oxygen content, may be due not so much to differences in activities of oxygen and aluminium in solution in iron as to the fact that the empirical curves do not represent true equilibrium in solution. So far as our own data are concerned, they give instead the aluminium which co-exists with the oxygen in solution plus oxygen in microscopic suspension as MnO and SiO_2 ; we suspect that Wentrup and Hieber's oxygen figures are high, owing to incomplete separation of reaction Al_2O_3, though their paper does not provide enough information to be certain.

Secondly, we must record our keen disappointment that this valuable fundamental work has not so far proved of any practical value in producing low-carbon killed coarse-grained steels. When the manganese, silicon, and aluminium remaining in the metal as alloy are deducted from the total amount of deoxidizing material, the difference—that is, the deoxidizing material actually oxidized and lost to the slag—is found to be equivalent to 0·20–0·30% of oxygen in the bath, about ten times the actual value. It is obvious therefore that the methods of addition permit about nine-tenths of the deoxidizers to act on the slag or air rather than on the steel, and it is somewhat pointless to determine whether the true oxygen in the bath is, say, 0·020 or 0·030% when in fact sufficient deoxidizer will be added to deal theoretically with 0·20–0·30%. It should be said that, apart from the economics of the question, we are not greatly concerned, because deoxidation is, in fact, very thorough, leaving in no case a total oxygen in excess of 0·006% in the steel as it rises in the moulds.

While we ourselves have not been able to make

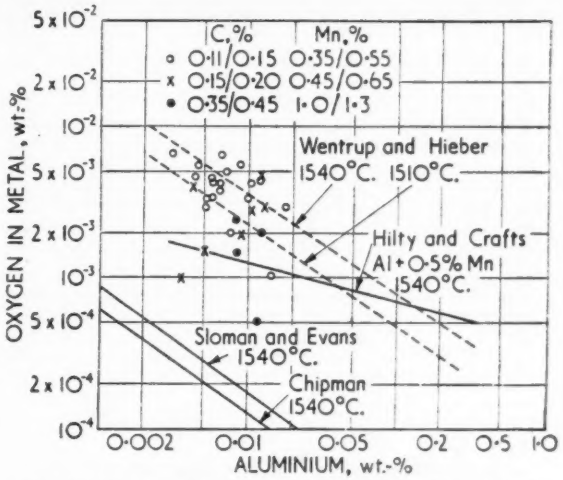


Fig. B—Oxygen contents of 0·10–0·25% silicon steels in relation to aluminium contents

immediate use of the valuable work of the Gases and Non-Metallics Sub-Committee and that of the authors of the papers before us today, the position may be different in the production of rimmed or balanced steel on the one hand, or controlled-grain-size killed steel on the other hand. It would be interesting to know from people engaged in these activities what progress has been made.

Dr. **P. Herasymenko** (The United Steel Companies, Ltd.) : The data on deoxidation equilibria critically collected by Dr. Richardson refer to laboratory investigations on simple systems. A comparison of these data with industrial practice indicates that we can correctly interpret the principal facts of steelmaking and also even make with confidence quantitative deductions on the position of deoxidation equilibria from the study of slag and metal compositions in open-hearth furnaces ; thus the distribution of manganese and chromium between the metal bath and slag in acid open-hearth furnaces follows exactly the same laws as were found in laboratory experiments (melts in silica crucibles).* Evidently the effect of the highly oxidizing furnace atmosphere is almost completely neutralized just above the slag surface by the reducing gas (*i.e.*, carbon monoxide) evolving from the boiling bath, and the slag/metal equilibria are not disturbed to any significant extent by the furnace atmosphere.

I propose to use this important circumstance to calculate the deoxidation equilibrium for vanadium from the experimental data on the distribution of vanadium between metal and acid open-hearth slags. These data were compiled in Table II of my paper,* but have not yet been discussed with this point of view. In the acid heats reported, the vanadium content in the metal varied between 0·10 and 0·22%, and that in the slag from 0·29 to 0·67%. One of the reactions which leads to equilibrium distribution of vanadium between slag and metal is :

$$\underline{V} + 3/2\ Mn^{II} = V^{III} + 3/2\underline{Mn},$$

where the underlined symbols refer to the metal phase and the Roman superscripts denote the valency of elements in the slag phase. The equilibrium constant of this reaction :

* " Basic Open Hearth Steelmaking." New York, 1944 : American Institute of Mining and Metallurgical Engineers (Seeley W. Mudd Series).

† *Journal of The Iron and Steel Institute*, 1950, vol. 165, pp. 81–90.

‡ *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1950, vol. 188, pp. 414–424 ; *Journal of Metals*, 1950, Feb.

* P. Herasymenko, *Journal of The Iron and Steel Institute*, 1947, vol. 157, pp. 515–525.

$$k_V^{Mn} = \frac{[V](MnO)^{5/2}}{(V^{III})[Mn]^{5/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

calculated from these data is plotted in Fig. C against the temperature. It is seen that k_V^{Mn} varies only slightly with temperature and the spread of the points does not exceed that observed in good laboratory work of this kind.

From the investigations of Körber and Oelsen the equilibrium constant :

$$k_{Mn}^{O} = \frac{[Mn][O]}{(MnO)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

is known with sufficient accuracy. Combining equations (1) and (2) we obtain :

$$k_V^{O} = k_V^{Mn} \times \left(k_{Mn}^{O}\right)^{5/2} = \frac{[V][O]^{5/2}}{(V^{III})} \quad \ldots\ldots\ldots\ldots(3)$$

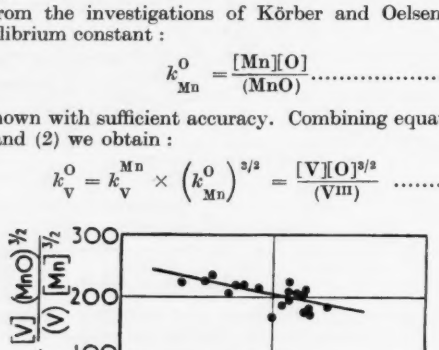


Fig. C—Equilibrium constant of $V + 3/2Mn^{II} = V^{III} + 3/2Mn$ in relation to temperature, for composition ranges [V] 0·10–0·22%, (V) 0·28–0·67%, [Mn] 0·33–0·50%, and (MnO) 27–40%

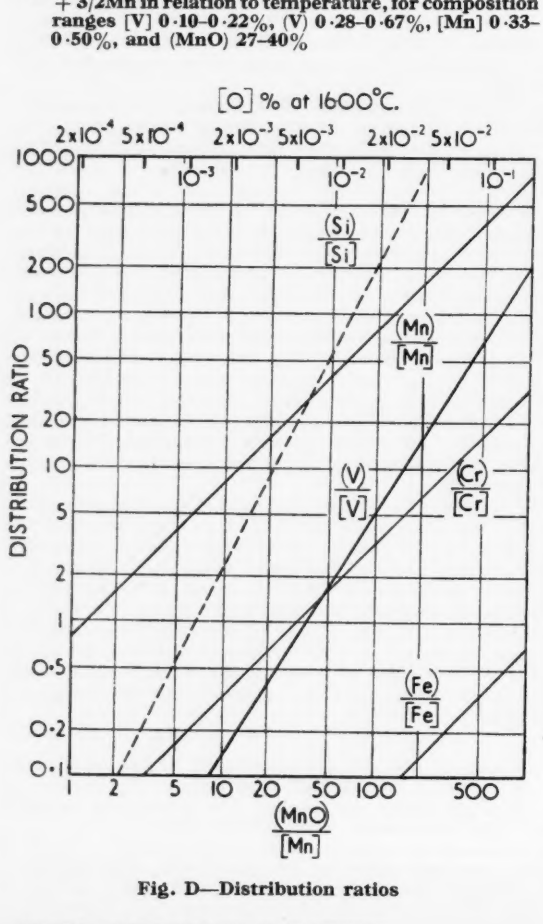


Fig. D—Distribution ratios

which characterizes the deoxidation equilibrium :

$$\underline{V} + 3/2\underline{O} = V^{III} + 3/2O^{II}.$$

Since the activity of oxygen atoms (ions) in acid slags in the presence of solid silica is practically constant, the concentration of oxygen in the slag is included in the value of the constant. The numerical values of k_V^O are as follows :

t° C. :	1550	1600	1650
k_V^O :	$2·6 \times 10^{-4}$	$5·0 \times 10^{-4}$	$8·7 \times 10^{-4}$

A large proportion of steels contain sufficient amounts of silicon to form, on cooling from the molten state and on solidification, silicate inclusions saturated with silica. For this case and for acid steel manufacture it is convenient to use a diagram in which the distribution ratio of the given element between the liquid silicate phase and the metal is plotted against the ratio (MnO)/[Mn]. Such a diagram is plotted logarithmically in Fig. D for several elements. This diagram is similar to Fig. 7 of Dr. Richardson's paper, because the abscissæ in our diagram indicate values proportional to the activity of oxygen in the metal which follows immediately from equation (2), namely :

$$\frac{(MnO)}{[Mn]} = k_{Mn}^{O}[O].$$

The proportionality factor, k_{Mn}^{O}, varies with the temperature, and therefore the oxygen activities have different values at different temperatures. The position of the curves in Fig. D characterizes the deoxidizing power of the given element in the presence of silicon and solid silica. This diagram is useful for practical applications ; the distribution ratio for a given element can be read off from the curves immediately, and they thus serve in the estimation of what proportion of this element will be lost to the slag (oxidized) at a certain (MnO)/[Mn] ratio in an acid slag. The latter ratio can be easily determined during the course of steelmaking in acid open-hearth furnaces.

In the same series of acid open-hearth heats mentioned above, aluminium was also determined in the metal and slag at the end of the boiling period, *i.e.*, about 4–5 hr. after melting down. The aluminium contents in the metal were not reported in my paper, because I did not consider the accuracy of the analytical determination of very small amounts of aluminium to be sufficiently high. The average content of aluminium in the metal in six tests was 0·0015 ± 0·0010% and that of alumina was 2·0 ± 0·10%. In spite of the relatively large spread of the aluminium determinations in the metal, we may use these data to check the order of magnitude of the aluminium deoxidation constant. Since the average MnO content in these tests was 32% and the average manganese content in the metal was 0·48%, we can calculate the oxygen activity of the metal by using the data of Körber and Oelsen for the equilibrium $\underline{Mn} + \underline{O} = MnO$. The average value so obtained was 0·016%[O], whereas the analytically determined oxygen content was about 0·010%. (The lower analytical oxygen content is due to the effect of carbon (0·40%) on the activity coefficient of oxygen.) From the above data the deoxidation ratio is :

$$\frac{[Al]^2[O]^3}{(Al_2O_3)} = \frac{(0·0015)^2(0·016)^3}{2} = 4 \times 10^{-12}$$

According to Wentrup and Hieber the same ratio at 1620 ± 10° C. is $1 - 4 \times 10^{-12}$, which is in reasonably good agreement.

I agree with Dr. Richardson that Wentrup and Hieber's data for the deoxidation constant of aluminium

must for the present be considered the most reliable. The recent results for aluminium obtained by Hilty and Crafts are probably too high. These authors themselves reported that there was a constant growth of alumina inclusions in the liquid metal, starting from the crucible walls. Evidently there was a diffusion gradient of oxygen through the porous crucible walls from the outside (from the refractories in which the alumina crucible was embedded), and oxygen or water vapour was not completely eliminated by the preliminary evacuation and by further sweeping out the furnace with argon. The rotation of the metal only helped the migration of alumina inclusions to the centre, where the samples for oxygen determination were taken. The use of rotating crucibles was in this case—where the deoxidation products were solid—an unnecessary complication, and experiments with a stationary crucible could have been arranged more easily to eliminate oxygen from the refractories.

Mr. **R. E. Lismer** (The United Steel Companies, Ltd.) : My remarks will be confined to the microscopical examination of the inclusions in the paper by Sloman and Evans. Members of the Solid Steel Study Group of the Gases and Non-Metallics Sub-Committee of the British Iron and Steel Research Association have had the opportunity of microscopically examining samples from three of the small melts from the series studied by the authors. The samples circulated were representative of the three main differences in the treatment of the melts, namely, ingot *E*, which contained the excess aluminium addition, ingot *J*, with the deficiency due to incomplete diffusion, and ingot *N*, in which an insufficient addition was made. The work did not add very much to the description given by the authors, but details of the results may amplify certain assumptions made in the paper.

The Group recognized the difficulties in the microscopical examination of the samples owing to the minute size of the inclusions, and suggested that the ingots should have been cooled slowly, in order to produce larger inclusions of the reaction type. The segregation of alumina particles into massive clusters may have been due to uneven initial dispersion of the aluminium addition. This cluster effect was a feature of the distribution of alumina within three ingots, representing rimming, semi-killed, and killed ingots, studied by Macnair.

In the co-operative work on the estimation of the type, quantity, and distribution of the non-metallic inclusions in Macnair's ingots, the microscopists counted, at high magnification, all the inclusions present within specified areas at regular intervals from the outside to the centre of each ingot, at top, middle, and bottom positions. The segregation of small alumina particles into numerous clusters caused such heterogeneity of inclusion distribution within two of the ingots that reproducibility in the assessment of the amount of inclusions was impossible. These segregations had been shown to be more pronounced towards the bottom of the ingot and, with higher aluminium additions, the intensity of segregation increased and persisted to a higher position up the ingot.

To return to the samples of Sloman and Evans, in ingot *E* the inclusions, mainly in segregates, consisted of dark translucent spheroidal particles of alumina, with a few spinels. Some of the alumina particles were vitreous in nature, and doubtless formed as a result of the high heat of reaction between the dissolved oxygen and the added aluminium.

In ingot *J* the segregates also contained more defined, almost opaque, idiomorphic inclusions of spinel crystals of $FeO.Al_2O_3$ composition. In addition, several dark, opaque idiomorphic inclusions, identified as corundum, were present, generally randomly dispersed, although some group formations of minute corundum particles were observed.

Probably the most suitable method of verifying that all the particles were aluminous and not siliceous is to immerse the specimens in a strong solution of hydrofluoric acid. Examination after this etch showed no attack on any of the general types of inclusions, confirming that they were predominantly alumina.

In ingot *N* the predominant inclusions consisted of FeO or duplex spinel crystals embedded within the FeO globules. Many of the globules were mottled and less regularly shaped, containing some particles that were opaque and others that were clearly iron. There were no methods of determining whether any of the particles were magnetite (Fe_3O_4), nor could they be identified separately from the hercynite particles. The duplex nature of the wüstite globules may have been due to the outer regions exhibiting a lower solid solubility of Fe within the FeO.

CORRESPONDENCE

Mr. **G. E. Speight** (The United Steel Companies, Ltd.) wrote : Sloman and Evans' experiments were designed primarily to study the nature of the deoxidation products, and in this they were remarkably successful. Their extension of the work to include calculations of the aluminium/ferrous-oxide equilibrium constant, although interesting, is perhaps not justified on account of the uncertainties regarding the distribution of alumina. However, the authors fully recognize this limitation and have sought to avoid undue emphasis on the numerical values of the constant so obtained. In Dr. Richardson's paper, and indeed in the verbal discussion which followed its presentation, there was hardly any reference to what is, after all, the primary function of deoxidation—namely, to regulate the reactions during freezing so that an ingot of the desired structure is obtained. It is on this very point that the data in Dr. Richardson's paper are so valuable in presenting clearly the close similarity but essential differences in the deoxidation reactions of carbon and silicon. The curious reversal in the content of dissolved oxygen as the concentrations of carbon and silicon increase, and the marked difference in the effect of temperature on the oxygen content in equilibrium with carbon and silicon have been clearly shown in Fig. 7. These phenomena can have a profound effect on the course of steelmaking and ingot freezing. Thus at 1600° C., with normal carbon and silicon levels, carbon and not silicon will control the amount of dissolved oxygen if the carbon is greater than 0·15%, whilst the reverse applies at carbon contents below 0·15%. At 1540° C. silicon becomes much more effective than carbon in controlling the reactive oxygen content.

An important example of how these equilibria may affect ingot structure arises where recarburization is necessary. Thus we see from Fig. 7 that at 1540° C. 0·1% of silicon is equivalent to 0·25% of carbon in being in equilibrium with 0·02% of oxygen. If recarburization to 0·5% carbon is applied, the carbon–oxygen equilibrium would be thrown out of balance and the metal if cast then would tend to be gassy and might even show blow-holes in the solidified ingot. This would be avoided by increasing the silicon content to about 0·25%, at which point it would be able to take over control of the reactive oxygen. All instances where unsoundness in ingot casting is under consideration should first be examined on the above lines.

In connection with the aluminium deoxidation constant, the following data from large low-carbon aluminium-treated ingots will be of interest to both Mr. Sloman and Dr. Richardson. The oxygen contents at tapping were not determined but would be of the

order of 0·030%. An addition of 2 lb. of aluminium per ton of steel was made to the ladle. Random billet samples from nine such heats were analysed for oxygen and soluble, *i.e.*, metallic, aluminium, the results ranging between 0·0025 and 0·008% of oxygen and 0·004 and 0·025% of soluble aluminium. Calculations of the constant :

$$k^{O}_{Al} = [Al]^2 \times [O]^3$$

for each of the nine analyses gave values between $0{\cdot}4\text{–}9{\cdot}8 \times 10^{-12}$; in fact most of the results were closely grouped between $3\text{–}7 \times 10^{-12}$. The average value, $5{\cdot}3 \times 10^{-12}$, agrees very closely with Wentrup and Heiber's constant at 1540° C. These results would seem to indicate that, at least in large (80-ton) ladles, the alumina formed on primary deoxidation by an addition of aluminium is eliminated before the ingot solidifies and that, provided that there still remains sufficient aluminium, the remaining oxygen is low and is such as would be in equilibrium with the metal at its freezing point.

As deoxidation is of such high practical significance it would not be out of place to refer to an early attempt to provide a quantitative basis. Some 50 years or so ago, Brinell put forward his density quotient $\text{Mn}\% + 5{\cdot}2\ \text{Si}\% + 90\ \text{Al}\% = T$, where the ingot structure obtained could be predicted from the value of T. For 10-in. ingots, if $T > 2{\cdot}05$ the ingots are deeply piping, if $T = 1{\cdot}66$ the ingots show minimum pipe, and if $T < 0{\cdot}28$ the ingots show deep-seated blow-holes. It could be argued that the coefficients in the foregoing expression are a measure of the deoxidizing power of the elements in relation to manganese, and on this basis 1% Mn $\equiv$ 0·19% Si $\equiv$ 0·011% Al. Each of these should therefore be in equilibrium with a similar amount of dissolved oxygen, and this idea is reasonably well confirmed by the data in Dr. Richardson's Fig. 7. Thus at 1540° C. the soluble oxygen contents in equilibrium with the above amounts of manganese, silicon, and aluminium are : 1% Mn (for acid slags) $\equiv$ 0·0055% O_2, 0·19% Si $\equiv$ 0·0065% O_2, and 0·011% Al $\equiv$ 0·004% O_2. The order of agreement in these oxygen values speaks well both for the validity of Brinell's ideas and the great practical value of the data collected by Dr. Richardson.

Dr. **P. T. Carter** (Royal Technical College, Glasgow) wrote : The use of activities instead of weight concentrations in defining chemical reactions involves the simultaneous appreciation of the meaning of activity coefficient. The adoption of two different standard states has resulted in two different activity coefficients, namely γ and f. Thus Dr. Richardson quotes a value for $\gamma_{[C]}$ of 0·61 at low concentrations based on pure carbon as a standard state, whereas $f_{[C]}$ based on the dilute solution as the standard state does not differ much from unity until [C] exceeds about 1%. It is therefore important to appreciate the distinction between $\gamma_{[C]}$ and $f_{[C]}$, and to know when it is advantageous to use one and not the other. In this connection it is not clear why $\gamma_{[O]}$ should be preferred in Fig. 3 of Dr. Richardson's paper.

A hypothesis put forward by Van Weimarn* concerning the relation between conditions of precipitation and the size of the precipitated particles has been successfully applied to problems of analytical chemistry. The hypothesis may be stated mathematically as follows :

$$d = J\frac{Q - L}{L},$$

where d is the dispersion coefficient (the higher the dispersion coefficient the smaller the size of particle produced), L is the ordinary solubility of substance being precipitated, Q is the total amount of precipitated substance momentarily produced in solution ($Q - L$ is therefore a measure of the extent of momentary 'supersaturation'), and J is a constant, the value of which depends on such physical factors as viscosity of solution, etc.

The hypothesis, with certain modifications, would appear to be equally applicable to problems concerned with the size of deoxidation products. Thus, although the result is known, it would predict the formation of very small particles, almost of colloidal size, in some of the experiments of Sloman and Evans.

* *Chemical Reviews*, 1925, vol. 2, p. 217.

AUTHORS' REPLIES

Dr. **F. Richardson** wrote in reply : Sir Charles Goodeve has raised the question of whether metastable equilibria can occur in high-temperature systems. In my view they can, but I know only of cases where a *solid* phase is involved. I cannot see how metastable equilibria involving *liquid* and gas phases only, can exist at high temperatures. Cementite, for instance, can separate from liquid iron saturated with carbon, although cementite is thermodynamically unstable relative to graphite and *iron saturated with carbon*. (It is of course stable with respect to graphite and *pure* liquid iron at high temperatures). Again, both liquid metals and liquid slags can be supercooled, the metastability in these cases arising from the difficulties of nucleating or growing the stable solid phase.

I particularly thank Dr. Kubachewski for his useful suggestions. I agree that the influence of alloying elements on $\gamma_{[O]}$ should most properly be plotted in terms of atomic percentages. If this is done, however, the carbon line comes just below that for chromium and not at the top. For the purposes of Table I, col. 5, it makes no difference to the position of carbon if the CO (or CO_2) is taken in the solid state. I do not agree with Dr. Kubachewski's comments on vanadium. His equation leads to precisely the same result as mine, which was amended after that proposed originally by Richardson and Jeffes (*see* reference 31 of their paper). I agree with the comments on boron. The newer heat of formation of B_2O_3 is compatible with $\gamma_{[O]} \sim 0{\cdot}9$, $\gamma_{[B]} \sim 0{\cdot}03$ at 1% boron and 1600° C. Regarding aluminium, I agree that Henry's law may not hold at higher aluminium concentrations, though more accurate data are needed before one can be sure. In my view, however, the most likely cause of error in $\gamma_{[Al]}$ lies in the indirect manner of its experimental derivation by Chipman.

Because TiO is the lowest oxide of titanium, it does not follow that it is the deoxidation product under most conditions. I have made new calculations on the deoxidation equilibria of TiO_2 and TiO using K. K. Kelley's most recent heats of formation (private communication). From these and Wentrup and Hieber's results it can be estimated that TiO should be the equilibrium solid product when the titanium activity relative to the pure liquid is greater than 0·1%. The product should be Ti_2O_3 when the titanium activity lies between 0·1% and 0·003%, and TiO_2 at lower values. Relative to the pure liquid, $\gamma_{[Ti]}$ then becomes $\sim 0{\cdot}01$ at low concentrations, and the activity coefficient of the oxygen is lowered by a factor of $\sim 0{\cdot}7$ at 0·1% (wt.) titanium.

In reply to Dr. Welch, I consider that the existence of one or more stable *exothermic* solid compounds between two metals is a fair pointer to low activity coefficients in the liquid solutions formed between the same pair of metals. Both phenomena arise from the same cause—a stronger interaction between the unlike than between the like atoms—so that the one phenomenon may be inferred from the other. I must stress that the statistical picture I have given denies the existence of any precise

compounds in the melt, identical with those found in the solid state.

I am in entire agreement with Mr. Speight's most valuable comments. I also agree with Dr. Carter concerning γ and f. I used the *ratio* of the values of $\gamma_{[O]}$ in Fig. 3, so that the activity coefficients throughout the paper should refer to the appropriate *pure* phases as standard states.

Mr. **H. A. Sloman** and Mr. **E. Ll. Evans** wrote in reply : We wish to thank Sir Charles Goodeve and other contributors to the discussion for their appreciative remarks. We agree with Sir Charles that much work remains to be done on the problem of the physical removal of deoxidation products. The complexity of the problem is illustrated by the fact that deoxidation by aluminium in the ladle results in removal of much of the oxygen (as Mr. Speight's figures show) despite the tendency of alumina to form agglomerates, which might be expected to float very slowly to the top. Calculation of the movement of FeO-containing particles is complicated by their being formed during, or even after, solidification.

Dr. Riley queried the establishment of equilibrium in alumina crucibles. Sintered alumina crucibles of the same quality are used in the preparation of N.P.L. Mark 2 iron, the analysis of which is given in our paper, and also in that of N.P.L. Mark 1 iron, which is of even higher purity. There is very little erosion of alumina into the melt, and no metallic aluminium in addition to that combined with oxygen.

Discussion on the Paper—

THERMODYNAMIC ASPECTS OF THE MOVEMENT OF SULPHUR BETWEEN GAS AND SLAG IN THE BASIC OPEN-HEARTH PROCESS*

By F. D. Richardson and G. Withers

Dr. **F. Richardson,** in presenting the paper, said that a correction was necessary in the formula in line 13 of column 1 of p. 69 ; it should read :

$$\frac{\text{Sulphur content of equilibrium metal for slag under consideration}}{\text{Sulphur content [S] for the curve used}}.$$

Dr. **U. R. Evans,** (Cambridge University) : I should like to emphasize the practical value of this paper, and to ask furnace specialists whether the ratio of CO/CO_2 favourable to the production of low-sulphur steel under high-sulphur gas can be achieved in practice, and what is the fraction of the hearth area over which it cannot easily be maintained. I wish to point out the economic importance of producing low-sulphur steel, since sulphur stimulates corrosion in some, but not all, circumstances, as is shown by the work of Mears,† Hoar,‡ Homer,§ and others. The chance of corrosion failure on a finished article of coated steel is the chance that a weak spot in the coat coincides with a susceptible spot in the metal, which often means a sulphide particle.

Dr. **B. Matuschka** (Leoben-Donawitz, Austria) : I agree with the authors on the influence of excess of oxygen or air in particular in the open-hearth atmosphere. In our investigations we found that about 100% excess of air at 1700° C. gives a figure of 0·025% of sulphur with a content of 3 g., and 0·018% with 2 g. These figures may be a little higher than those which have been found by theoretical calculations, but there are many factors affecting the position so far as sulphur is concerned.

As mentioned by the authors on page 70, the temperature has a very important influence. There are also the basicity and the ferrous oxide content of the slag, the sulphur and the manganese content of the whole charge, and, not least, the amount of slag which is used.

There are two principal methods which can be used for the removal of the sulphur, the calcium sulphide and the calcium sulphate methods. It is not possible to combine the two. The calcium sulphide method can be used in electric-furnace practice. If you have a small amount of oxygen or ferric oxide in the slag it seems to me that the calcium sulphide cannot be stable, and therefore in electric-furnace practice it is necessary to have a very good white slag or a carbide slag in order to remove sulphur. On the other hand with an excess of oxygen in the atmosphere of the open-hearth furnace the sulphur will be in the slag as calcium sulphate. These conditions are favourable when you have a high temperature and a very basic slag.

I had the same problem many years ago when it was necessary to produce rimming steel of very low sulphur content, and we found it necessary to increase the basicity of the slag and to work with a very high temperature. If the slag can be removed during the process, advantage can be taken of that, but in our plant we could not remove the slag, because we had a fixed open-hearth furnace, and the only way to achieve good desulphurization was to increase the amount of slag. The question of slag is bound up with the question of cost. If you need a very low sulphur content you must work with a great deal more slag, and then your loss of iron is worse than in normal cases. That is also true if you need a very high temperature.

The question of resulphurization is mentioned in the paper. To avoid it you must have a high temperature, but there are difficulties at the end of the melt, because there is no longer any movement in the slag and all the heat goes to the roof. With an acid roof, which is the normal condition, it is possible that during these last minutes some silica will come down from the roof, and if the slag is slightly acid the conditions will naturally be changed very much, so that it is possible that in the last few minutes the sulphur will come back. It is also possible that if magnesite or dolomite from the bottom comes in the slag, the slag conditions become unfavourable. Thirdly, at the time of tapping, if slag and steel are mixing it is possible that the condition will be worse.

In Austria the conditions have been more favourable. It is now our general practice to have basic roofs of magnesite bricks, and it is possible to run at a higher

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* *Journal of The Iron and Steel Institute*, 1950, vol. 165, pp. 66–71.

† *The Iron and Steel Institute*, 1935, *Carnegie Scholarship Memoirs*, vol. 24, pp. 69–85 ; *The Iron and Steel Institute*, 1935, *Special Report No.* 8, p. 111.

‡ *Journal of The Iron and Steel Institute*, 1936, No. I, pp. 239P–291P ; *ibid.*, 1939, No. II, pp. 55P–94P ; *ibid.*, 1941, No. II, pp. 133P–155P.

§ *The Iron and Steel Institute*, 1932, *Carnegie Scholarship Memoirs*, vol. 21, pp. 35–37 ; *The Iron and Steel Institute*, 1934, *Special Report No.* 5, pp. 225–240.

temperature with an all-basic open-hearth furnace, without danger of silica in the slag. If in the open-hearth furnace there is sufficient excess air and the temperature is high enough, the conditions for desulphurization are more advantageous in basic furnaces. From the experience we have gained I think that it is possible to reach a lower sulphur content, but to do this all the factors must be favourable.

Dr. **P. T. Carter** (The Royal Technical College, Glasgow) : The authors have focused attention on the importance of the CO/CO_2 ratio of the gas phase in so far as it affects the gas/slag sulphur equilibrium in steelmaking. It is also important to know what gas atmosphere should be regarded as being the determinant in this equilibrium between gas and slag. If for instance there is no boil, then it is the furnace gases passing over the slag which should be considered ; on the other hand if a boil is in progress the gas evolved during the boil must also be considered, and it would be of interest if the nature of the gas coming off during both the lime and the ore boils could be determined. During the lime boil CO_2 is evolved, part of which is reduced to CO in its passage through the metal. The proportion so reduced is not known, but it is fairly certain that the gas evolved during the lime boil is more oxidizing than that evolved later, and it is possible that this gas would be beneficial in effecting sulphur removal. The later boil, during which the gas evolved is principally CO, would not be expected to assist sulphur removal. The CO/CO_2 ratio of this gas is mainly determined by the oxygen content of the steel, according to the equilibrium $CO + \underline{O} = CO_2$:

$$\frac{p_{CO}}{p_{CO_2}} = \frac{k}{[O]}.$$

The effective gas atmosphere at the gas/slag interface depends on how far mixing has proceeded between the gas evolved during the boil and the furnace gases passing over the bath. Assuming that the latter were sufficiently oxidizing to favour sulphur removal, a vigorous boil of the latter type would be expected to produce conditions which were less conducive to sulphur removal from slag to gas and a weaker boil to help sulphur removal. If the furnace atmosphere were such as to favour transfer of sulphur to the slag, no boil would result in sulphur pick-up ; a boil might reduce this, and if vigorous enough might even cause loss of sulphur to the gas phase.

The mechanism for sulphur removal suggested is one in which oxygen passing from the gas *via* the slag to the metal is considered as a means of ' pumping ' sulphur out of the metal into the gas. It should be noted that as oxygen enters the metal sulphur is more reluctant to leave the metal, *i.e.*, the ' pump ' becomes progressively less efficient. In steelmaking, however, the oxygen does not accumulate but assists in the removal of carbon.

Dr. **A. H. Leckie** (British Iron and Steel Research Association) : This paper is remarkable in illustrating the direct practical application of thermodynamic calculations. The authors end up with target figures for combustion control and suggest a possible way of removing sulphur which I should like the practical steelmakers to think about. Instead of the common practice of using masses of lime and very heavy slag, a less-deep slag layer might be worked, either by using less slag-forming materials or a larger hearth area, or both. This would allow the sulphur to pass to the gas to a much greater extent, and it should be possible to desulphurize to a considerable extent by allowing the sulphur to burn off the surface. Dr. Richardson has shown that under oxidizing conditions this is quite practicable. The paper suggests that the present technique of adding large quantities of lime may lead to that lime just desulphurizing the furnace atmosphere instead of the steel. An important link between chemical thermodynamics and practical furnace design is brought out, and it is shown that the chemistry of the process requires efficient ports, which give high oxygen potentials in the furnace atmosphere. The need for more of the practical type of experiment where probes are put in the furnace to determine the composition of the atmosphere is also shown, and it is clear that we shall have to do more of this kind of work to verify the author's conclusions.

CORRESPONDENCE

Mr. **C. E. A. Shanahan** (British Iron and Steel Research Association) wrote : The calculations and conclusions of this very interesting paper depend entirely on the theory that slag will not absorb significant quantities of sulphur without yielding equivalent quantities of oxygen. It seems worth while therefore to outline the reasons for adopting this hypothesis, and the authors have accordingly stated the experimental constancy of K_T (slag/metal) in their equation (3), emphasizing that (O″) and (S″) are expressed in atom fractions. This constancy does not by itself support the above hypothesis, since it may be the result of two independent reactions :

$$[O] \rightleftharpoons (O)$$
$$[S] \rightleftharpoons (S),$$

i.e., the simple partition of sulphur and oxygen atoms between metal and slag. Thus to dispel this possibility, mention should be made of the experimental inconstancy of the ratios (O)/[O] and (S)/[S], as this is vital in deriving the above hypothesis. If this question had been approached in terms of, for example, Temkin's ionic theory, the link between the oxygen and sulphur reactions (*via* the iron ions) would have been obvious, the values of (O)/(S) being independent of the choice of atom fractions or Temkin's ionic fractions.

The reactions between furnace gases and liquid metal are of importance not only in the charging and melting periods, but during refining. This is particularly true during the ' boil ' in acid practice, when many iron particles are thrown through the shallow slag. Indeed Whiteley and Hallimond* reported that 50% of the carbon may be eliminated by the gas oxidation of these particles. This was based on practical estimates of the weights and carbon contents of metallic iron suspended in the slag at any instant and the not unreasonable assumption of a replacement time of $\frac{1}{3}$–$\frac{1}{2}$ sec. The value of the use of thermodynamics for this type of reaction is very limited, since, obviously, under equilibrium conditions no free iron could exist. However, in order to assess the conditions of sulphur pick-up during charging, I am using the following conceptions which may be of interest. At about 10^{-8} atmosphere of oxygen, the iron becomes covered with oxide and the gaseous sulphur from then onwards is absorbed by oxide instead of iron. Apart from assuming (very questionably) that the activity of sulphur in the oxide film is identical with that in the metal, *i.e.*, simple partition of sulphur between metal and oxide, the film and gas are considered to be out of equilibrium with the metal beneath them, *i.e.*, that iron can exist, protected by the oxide film from oxygen pressure $> 10^{-8}$ atmosphere. Sulphur absorption may possibly be represented by $2Fe^{++} + \frac{1}{2}S_2 = 2Fe^{+++} + S^{--}$, from which

$$K_T = \left(\frac{Fe^{+++}}{Fe^{++}}\right)^2 \frac{(S^{--})}{P^{\frac{1}{2}}_{S_2}}.$$

(Fe^{+++}/Fe^{++}) can be obtained for any particular

* *Journal of The Iron and Steel Institute*, 1919, No. I, pp. 199–253.

value of CO/CO_2 from the data of Chipman and Fetters.* Thus K_T is calculated from the value of (Fe^{+++}/Fe^{++}) at the instant of free-oxide formation, (S^{--}) equalling the activity of the sulphur in the free iron ; $P^{\frac{1}{2}}_{S_2}$ is calculable from the latter and the data of Chipman and Li†. For a particular sulphur value it is thus possible to calculate the equilibrium p_{S_2} for any CO/CO_2 ratios, and therefore to plot curves involving ΣS_g similar to those of the authors. Results so far indicate that oxide films tend to reduce sulphur absorption from the gas phase. It is felt that although this method of calculation is very crude and is probably of value only when the sulphur concentrations are very low, lack of experimental data prevents more precise assessments.

AUTHORS' REPLY

Dr. **F. Richardson** wrote in reply : Dr. Matuschka's experience of the influence of excess air in the open hearth is most interesting as it is in qualitative agreement with our deductions. He has referred to the retention of sulphur in the slag as sulphate. I do not think sulphate can be important in slags at steelmaking temperatures. For a slag in equilibrium with iron, the proportion of sulphur held as sulphate is negligible. As we calculate in our paper, and as since shown by experiment, the sulphate sulphur only exceeds the sulphide sulphur when the ratio CO_2/CO exceeds about 25 : 1 at 1627° C. This is a highly oxidizing condition relative to metallic iron, and one which cannot be realized in the slag except on the top surface when gas conditions are relatively oxidizing. In cases where such conditions are realized, however, one cannot expect to retain the sulphur in the slag as sulphate ; for with normal sulphur contents the slag would be in equilibrium with gas containing well over 100 g. of sulphur per cu. m. as SO_2. Since such high sulphur contents in the gas can rarely, if ever, occur, no substantial proportion of sulphur can be held by the slag as sulphate.

I agree with Mr. Carter's remarks. I, also, would much like to know how strongly or otherwise the gases coming from the bath influence the gas atmosphere immediately above the slag. Calculation of the quantities of CO and CO_2 evolved per sq. ft. per sec. suggest that they may not be overwhelming. Probe experiments of the type suggested by Dr. Leckie could give the answer. I like Dr. Leckie's suggestion of working with a thin, not too basic, slag ; I am sure that in this way, provided combustion conditions are suitable, it should be possible to send useful quantities of sulphur away in the furnace gases. But I must warn that if such an arrangement is tried under gas conditions that are not sufficiently oxidizing, the last state will be worse than the first.

In reply to Mr. Shanahan I must stress that we did not resort to ionic theory, because it is unnecessary. Furthermore, there is no possibility of the experimental constancy of K_T in our equation (3) arising from the two independent equilibria proposed by Mr. Shanahan. It hardly requires statement that

$$[O] \neq K_o(O'')\text{, or that}$$
$$[S] \neq K_s(S'').$$

For instance, (O'') could be large, with virtually no iron in the slag, and [O] would then be very small. Correspondingly, (O'') could be small with much iron in the slag, when [O] would then be quite large.

It is unfortunate that more precise data are not available on the amount of metal which is projected as drops into the furnace gases and is thus a potential cause of sulphur pick-up during refining. The data mentioned by Mr. Shanahan cannot apply directly to basic practice where thicker and more viscous slags are used. It is nevertheless conceivable that sulphur pick-up by metal drops is important. If so, it follows that sulphur losses from slag drops and from the slag surface, must also be important, since the net passage of sulphur between slag and gas in the refining period is generally small. It is thus as important as ever to have the furnace gases well burnt before they come into contact with the slag.

As our footnote on p. 66 shows, we also had concluded that oxide coatings, on melting or liquid metal, should have some protective value.

* *Transactions of the American Society for Metals*, 1941, vol. 29, p. 964.

† *Transactions of the American Society for Metals*, 1937, vol. 25, p. 435.

Discussion on the Paper—
THE TRANSFORMATIONS $\alpha \rightarrow \gamma$ AND $\gamma \rightarrow \alpha$ IN IRON-RICH BINARY IRON–NICKEL ALLOYS*

By N. P. Allen and C. C. Earley

Dr. **N. P. Allen** (National Physical Laboratory) introduced the paper.

Dr. **K. Hoselitz** (Permanent Magnet Association) : An outstanding feature of this paper is the very painstaking precision with which the work has been carried out. It is only by working very carefully that the authors could demonstrate so clearly how the $\alpha_2 \rightarrow \gamma + \alpha$ reaction can occur in two distinct types of reaction, the rapid and the slow type. The rapid transformation was found to be similar to the martensite type of $\gamma \rightarrow \alpha$ transformation which takes place on cooling, as is well known.

The most interesting and extensive part of the work is devoted to the study of the slow type of transformation. Here the authors confirm the results of previous work by Hoselitz and Sucksmith,[1] that the homogeneous supersaturated α_2 solid solution splits up into the two equilibrium phases, α and γ, during isothermal transformation. This breakdown, they confirm, occurs by the progressive separation of the γ-phase of equilibrium nickel content, while the matrix approaches the equilibrium α concentration. It is perhaps a minor omission that the prior work establishing these conditions expressively seems to have been overlooked by the authors.

Since alloys cooled from the single-phase γ-region into the α–γ phase field do not, according to the present paper as well as prior work by Sucksmith and his co-workers,[1,2,3] change to equilibrium, except, perhaps, after very much longer times, I would ask the authors whether it does not appear logical that equilibrium conditions, as well as transformations, can most effectively be studied by starting with alloys which have been brought into the α_2 state by cooling to sufficiently low temperatures, as was done in the present work.

* *Journal of The Iron and Steel Institute*, 1950, vol. 166 Dec., pp. 281–288.

XUM

It is of great importance that the authors find that during isothermal transformation at 450° C. the equilibrium γ-phase produced is so rich in nickel that it does not transform into the α form during cooling to room temperature, which means it has more than 28% of nickel; but on cooling to sub-zero temperatures it does transform into the α form, hence it must contain less than 32% of nickel. This fact appears to be in disagreement with the equilibrium diagram by Owen and Liu,[4] shown in Fig. 1, which the authors state is the equilibrium diagram generally accepted.

I was greatly impressed by the methods with which the authors identified the microstructure of the α_2-phase. Moreover, the appearance of a macroscopically duplex structure in those cases where the transformation of α_2 occurs in two stages demonstrates how extremely powerful the metallographic method can be if carried out with such exemplary care.

The microscopic evidence of the process of nucleation and growth is noteworthy and confirms the results of the authors' experiments as well as those of the magnetic investigation by Hoselitz and Sucksmith.[1] I feel that such visual micrographic evidence is always more convincing and direct than that of any other experimental method.

The authors show in Figs. 12 and 13 that increasing the temperature has the same effect on the rate of nucleation as increasing the nickel content. Since the illustrations are given to demonstrate this quantitative effect, the sections shown here can be assumed to be representative of the specimens. Now in Figs. 12*a* and 13*a* a 4·9% nickel alloy is shown after four weeks at 670° C. This treatment is amply sufficient to reach equilibrium, and the amount of γ-phase (shown as nickel-rich α_2 of course) should, according to the authors, be 25% of the alloy. Figures 12*a* and 13*a*, however, show only about 6% of the nickel-rich phase. In Fig. 13*b* a 7·4% nickel alloy shows that about 40% of the nickel-rich phase has precipitated. These rough quantitative estimates allow the concentration of the equilibrium α-phase to be calculated, assuming that the γ-phase has about 12% nickel, which is the γ-equilibrium composition at 670° C. according to most published equilibrium diagrams. The rough estimate gives, in both cases, an α-phase composition of about 4·5% nickel, in close agreement with the value of about 5% suggested by Hoselitz and Sucksmith,[1] but in disagreement with the phase boundary shown in Fig. 1. I would be glad to know whether the authors can offer an explanation for the quantitative disagreement between their work and the equilibrium diagram which they accept as basis.

The last part of the paper deals with the kinetics of the slow transformation. Taking the rate of diffusion as proportional to the amount of untransformed α, values of activation energy differing widely are deduced for experiments within a comparatively narrow temperature range of 590–620° C. Do the authors think that the fast type of transformation and the initial nucleation process have an influence on the calculated activation energy of 71,000–95,000 cal./mol. ? Hoselitz and Sucksmith also used the law of mass action for the calculation of activation energy, but the experiments were carried out at lower temperatures and over a much wider interval, namely 365–525° C. Here the fast type of transformation is presumably not taking place, and hence the result was less dependent on the actual temperature of the experiment. The value found for the activation energy was 34,000 cal./mol. In view of the spread of the authors' values and the different temperatures involved, the agreement does not appear to be too unsatisfactory.

The probability calculations determine in a convincing manner that the size of the stable nucleus is about 300 atoms. Why did the authors adopt for each transformation temperature a value for the nickel content of the precipitating γ-phase, when it is known that the precipitating phase has the equilibrium composition ? Probably I have overlooked some point in the paper, but I would be glad if this apparent contradiction can be explained. I think, nevertheless, that there can be no doubt that the value of 300 atoms is essentially correct.

Mr. **E. H. Bucknall** (The Mond Nickel Co., Ltd.) : In my opinion this is one of the most brilliant and original papers that has ever been before this Institute. Many who read this paper will feel that the authors have put their finger on the essential difference between martensitic and isothermal transformations over a wide field. There is, however, one point which should in my opinion be borne in mind, namely that in this work they are dealing with a substitutional solid solution, whilst usually when we are dealing with steels our interest is in an interstitial solution. This should not make much difference in the separation of a phase which is not very high in solute content, but it may make very large differences in the case of phases rich in solute, as, for example, the separation of graphite.

The separation of a second phase rich in solute, when this is a thermodynamic requirement, would appear in general to be comparatively easily achieved from a substitutional solid solution as compared with an interstitial solid solution. For the former there will always be a definite calculable probability of the appearance of a patch with the right composition. Some at least of these patches must match the configuration of the precipitable phase to a degree sufficient to act as nuclei for its formation by epitaxis. Only where configurational differences are large will there be any need for the introduction of an intermediate body as a step in the precipitation process. Slight supersaturation would be expected in general to initiate precipitation, and the diffusing ions would maintain conditions for precipitation at the faces of the growing nucleus. Since diffusion is by place exchange between solute and solvent ions in substitutional solid solutions, the movement of solute ions up to the precipitation interface automatically provides space for the growing nucleus by moving back an equal number of solvent ions. Whether the space would be adequate for stress-free precipitation depends on the relative specific volumes of the original and final phases, but it is clear that even when there is a fair difference in specific volume the development of stresses would be only a second-order effect, and it is unlikely that any important factor restricting the growth of the precipitating phase would arise.

In the case of precipitation from an interstitial solid solution on the other hand, there is no probability whatever of the chance appearance in the body of the lattice of a segregate patch having the composition of the pure solute, or anything at all closely approaching it, since, by definition, ions of the solvent must intervene between those of an interstitially dispersed solute. For instance, in the case of carbon and austenite we believe that at the most one can have the composition FeC existing in the lattice. Diffusion in this case will not do much to provide accommodation for the growing precipitate, and it seems likely that that phase will have to do work against stresses which are being generated in the lattice, and that these may restrict growth. Because of the impossibility of setting-up patches of pure solute in the body of the lattice, in that case external nucleation at defects in the lattice grain boundaries or at the surfaces of intermediate bodies become essential.

The authors make references to transformations from α_2 to $\alpha + \gamma$ at 435° and 450° C., but give little detail

below 590° C. Could they supply more information on this point, and say whether they are extending their work to the important field of carbon-containing nickel–iron alloys.

CORRESPONDENCE

Dr. **S. A. Main** (Hadfields, Ltd.) wrote : Have the authors considered the possibilities of the thermomagnetic method of examination, as used to much advantage by Chevenard and others ? It would seem particularly promising for this iron–nickel series of alloys. Simple observations of this kind were made in Hadfield's examination of the iron–manganese series, and gave some useful indications as to constitution. I was glad to hear from Dr. Allen that his own examination of this system is in progress.

AUTHORS' REPLY

Mr. **C. C. Earley** wrote in reply : I should like to thank the contributors to the discussion on our paper. The literature on the iron–nickel system is very extensive indeed : Griffiths[5] gives at least two hundred references. We have deliberately refrained in this work from giving a comprehensive bibliography, but we are familiar with the excellent work done by Hoselitz and Sucksmith, and the thermomagnetic method of examination, which has been applied to iron–nickel alloys by various workers.

Our work has shown that alloys, held anywhere within the $\alpha + \gamma$ phase field, will transform isothermally on heating. Just inside the boundary, transformation will occur provided that sufficient time is available, but the dilatometric method is generally not sensitive enough to detect very slow changes. Microscopic examination has shown definite signs of precipitation of a second phase after a lengthy induction period. The difficulty in the iron–nickel and iron–manganese systems is that the diffusion rates of Ni and Mn are exceedingly slow, particularly below 500° C.

With reference to cooling to sub-zero temperatures alloys with up to 28% of Ni, transformation from γ to α occurs on cooling to room temperature by the supposed martensitic shear type of transformation, and on further cooling to − 196° C. or lower temperatures no further change takes place. It is only with alloys of 28–30% of Ni, where the γ-solid solution at room temperature is stable, that it will decompose to α_2 on cooling to sub-zero temperatures. Alloys with up to 32% of Ni are completely transformed at − 196° C. ; with slightly higher Ni contents the alloys will transform partially, but not completely, at − 196° C. The austenite in the alloy annealed at 450° C. did not decompose at room temperature, but was partially decomposed at − 196° C., and its Ni content was thus somewhat greater than 32%.

The present work has not been to establish the equilibrium diagram specially, but it does agree well with the diagram by Owen and Liu. In a few cases we would like to correct their diagram somewhat but only by about ½%, the work having shown that the $\alpha + \gamma/\gamma$ boundary should be moved slightly to the right. In the region of about 590° C. the times to attain equilibrium are quite long, and the results of previous workers show discrepancies in the composition of the separating γ-phase owing to the extreme sluggishness of the reactions.

With reference to Figs. 12 and 13, in which the 4·9% Ni alloy has been isothermally transformed with these very slow reactions, only a few small islets of the γ-phase separate and it is difficult to take representative photomicrographs : Figs. 12*a* and 13*a* are illustrative rather than representative.

In choosing the composition of the precipitating γ-phase for the purpose of the calculations we relied upon our own observations rather than upon the published diagrams, when any uncertainty existed. We chose for each temperature the minimum nickel content for which no evidence of segregation into two phases of different nickel content could be found. Our values did not differ from those of Owen and Liu by more than ½% of Ni.

The general features of the iron–nickel system are not a peculiarity of this system. With iron–manganese alloys two different types of transformation occur, the martensitic and the slow diffusion change, and there is a narrow temperature range of about 10° C. in which the two types of phase change can occur successively. According to the literature, the iron–platinum system exhibits the same general hysteresis on heating and cooling, and the diagram is very similar. There is no doubt that transformation by the two different methods is a general feature of certain iron-rich alloys, particularly those with transitional metals.

Some preliminary work on iron–manganese–carbon alloys with carbon contents up to 0·05% has shown that as soon as carbon is put into iron–manganese alloys the whole system behaves as though the parent binary system were the iron–carbon system. Superposed on that are the general features of the iron–manganese system, and the interpretation microstructurally is rather complex.

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2. A. T. Pickles and W. Sucksmith : *Ibid.*, 1940, Series A, vol. 175, p. 331.
3. K. Hoselitz : *Journal of The Iron and Steel Institute*, 1944, vol. 149, p. 193.
4. E. A. Owen and Y. H. Liu : *Ibid.*, 1949, vol. 163, p. 132.
5. W. T. Griffiths : First Report of the Alloy Steels Research Committee, *The Iron and Steel Institute*, 1936, *Special Report No.* 14, p. 74.

Joint Discussion on the Papers—

THE ACCELERATION OF THE RATE OF ISOTHERMAL TRANSFORMATION OF AUSTENITE*

By M. D. Jepson and F. C. Thompson

and THE BREAKDOWN OF AUSTENITE BELOW THE M_s TEMPERATURE†

By F. C. Thompson and M. D. Jepson

Dr. **M. D. Jepson** (Hadfields, Ltd.) briefly introduced the papers.

Dr. **L. B. Pfeil** (The Mond Nickel Co., Ltd.) : I am interested in the section of the first paper relating to the effect of stress on rate of transformation of austenite, and particularly in the suggestion that conclusions drawn from studies on small specimens may not necessarily

* *Journal of The Iron and Steel Institute*, 1949, vol. 162, pp. 49–56.

† *Ibid.*, 1950, vol. 164, pp. 27–35.

be applicable to large masses. While it is admittedly difficult in any case to apply the results of laboratory determinations of thermal transformation to the behaviour of large masses, it would seem that if the influence of stress is as important as the authors indicate, present methods of applying laboratory data to the behaviour of industrial forgings during heat-treatment will require drastic revision. In this connection I find some reassurance in a study of the transformation curves of Fig. 19 of the paper. While the effect of a tensile stress of 10 tons/sq. in. appears to be real, those who have had experience with isothermal transformation diagrams on a series of steels made to the same specification may feel that the difference shown in Fig. 19 is possibly not of great significance. I hope that contributors to the discussion will express their views on the importance of stresses, as influencing transformation during the heat-treatment of forgings, considering that question in association with the suggested importance of the size effect and its practical implications.

In reading the authors' discussion and results I find somewhat confusing the switch from stress (in the first paragraph) to deformation by shear (in the second). I would ask whether they consider that the acceleration of transformation, which they found, is due to elastic strain or whether they suggest that under a tensile stress of 10 tons/sq. in., at a temperature of 220° C., plastic deformation occurred during the 2-hr. holding period. On the whole they would appear to take the latter view, since they refer to the significance of the elastic limit of austenite. They are, in fact, concerned with the further transformation of a mixture of austenite and martensite, and it is by no means clear to me that in this particular and peculiar structural condition alloyed steels would exhibit a higher elastic limit than carbon steels. Also, the authors suggest that even in absence of externally applied stress the transformation of austenite at low temperatures is initiated by stress. This conclusion I find most difficult to accept. Considering steel in the form of, say, thin wire, with a sufficient alloy content to permit slow cooling down to M_s without transformation, the authors suggest that on cooling to a temperature only a few degrees lower than M_s, stresses are built up to a level so high that they may even lead to plastic deformation.

To turn to the paper on breakdown of austenite below the M_s temperature, it is clearly established that austenite can transform below that temperature, and the question to be decided is the mechanism of this low-temperature isothermal transformation. The authors' view is that it involves formation of martensite, followed by tempering of the martensite to give a bainitic product. They attempt to dismiss the hypothesis that bainite forms directly from austenite by a well-reasoned criticism of evidence based on etching effects, followed by some comments on the direction taken by **S** curves extended below M_s, but the evidence they provide in this latter connection (for example in Fig. 13) is not, in my view, very convincing. One adjustment which they have made of the low-temperature data in Fig. 13, giving the dotted line, may be regarded as lessening the anomaly. Perhaps other contributors to the discussion may advance further arguments calculated to convince the authors that any break in continuing the isothermal curve below M_s is insignificant. I find that a serious hindrance to acceptance of the authors' view is the fact that after quenching to a temperature below M_s, in the course of which martensite is formed, it is necessary to wait for a period, which may amount to hours, before any further transformation of austenite occurs. The question arises : What is going on during that induction period ? The authors would have us believe that tempering of the already existing martensite is taking place and that this leads to building up of internal stresses, eventually to a level which causes breakdown of more austenite to martensite. Personally, I find it preferable to think in terms of tempering of martensite reducing internal stresses in the residual austenite. Alternatively, the authors appear to suggest that during the induction period diffusion is taking place in the austenite, but I am not clear whether they take the view that such diffusion leads to development of internal stresses (which, in turn, lead to formation of martensite), or whether they believe that martensite can form as a direct product of diffusion. For my part, I find it much easier to accept the view that martensite is a product characterized by instantaneous formation during cooling, and that subsequent isothermal transformation below the M_s temperature proceeds by the same mechanism as that involved in production of bainite above M_s.

Mr. **C. E. Mavrocordatos** (English Steel Corporation, Ltd.) : The authors' aim in their second paper is to prove that the product formed isothermally after a certain amount of martensite has been formed during quenching at temperatures below the M_s point is martensite, and not bainite as hitherto assumed. I think that a few points need further elucidation before we can accept or reject their hypothesis. For instance, the authors assume that there is a difference in the transformation product above the martensite line—which they are presumably content to call " bainite "—and the isothermal transformation product below the M_s, without trying to prove this. In Fig. 11 they show a series of test pieces held at 150° C. for varying times up to 25 hr., and they explain these photographs by the hypothesis of the formation and subsequent tempering of the martensite formed. The photographs would have been a proof of their contention if they had been accompanied by a similar series of photographs of the phenomena taking place at isothermal temperatures above the M_s and had shown conclusively that the mechanisms of formation in the two cases were completely different.

Again, by calculating the rate of transformation of the isothermal part of the transformation (a calculation which on their admission is exposed to very considerable errors), they claim to have found a discontinuity in the transformation characteristics below and above the M_s line, and they disregard completely the continuity shown in the classical **S** curve of steel *A* in Fig. 7.

The complete dilatometric curve of an isothermal transformation test at temperatures below the M_s, reproduced in Fig. 1 of the paper, shows clearly that transformation takes place over three distinct stages. During the first stage there is a very rapid increase in length, followed by the second stage, the duration of which varies with the steel and the bath temperature and which conforms with the extrapolated time of the period of incubation at temperatures above M_s. The third period of transformation is marked by a new increase in length, and the mechanism of it appears to be precisely similar to that of the reaction taking place at temperatures just above the M_s point.

It is stated by the authors (page 34) that the formation of the product of the isothermal transformation is due to " shear which has been initiated by stress." If that were so, the stress must be greatest immediately after the formation of the anisothermal martensite, *i.e.*, before the second period of inactivity, a period which could be taken as having two effects on the mass, *viz.*, some stress relieving and tempering of the already formed martensite. In either case, as time goes on the system must be under a diminishing stress.

The magnetic test described in the paper was unfortunately stopped before the onset of fast isothermal

transformation; it would be interesting to see what happens when this period of fast transformation takes place. As it is, the test only shows the sudden increase of the magnetic properties on the formation of the anisothermal martensite and the gradual increase during the tempering time. The **S** curve of Fig. 7 shows that the isothermal transformation at 150° C. starts after about 3 hr. and ends at about 40 hr., whilst the magnetic test was interrupted after 3½ hr.

Mr. **E. H. Bucknall** (The Mond Nickel Co., Ltd.): It would be interesting to have definite figures for the M_s temperatures of the steels. McReynolds* has produced evidence that stress can alter M_s, raising it by up to 70° C. in iron–nickel alloys. It is said in connection with Fig. 2 in the first paper that temperature oscillation mainly affects transformation below M_s. The second paper gives us the impression that the M_s for steel *A* is at 200° C. Steel *B* would be expected to have a lower M_s temperature, and one wonders therefore whether the authors are on safe ground in their conclusion.

Information on the composition and M_s temperature of the second steel in the second paper would also be appreciated; all that we are told is that this steel is of eutectoid composition. As such, austenitizing at 800° C. might conceivably give an M_s temperature as low as 150° C. or possibly as high as 350° C. In consequence the reader is in some difficulty in understanding the import of the results given in Fig. 11 and the Table of hardness values on page 32 of the second paper, which refers to this steel when exposed at 150° C. after austenitizing. My impression from Fig. 11 is that 150° C. is only a little below the M_s of the steel. In that case I take the hardness results to represent a complex summation of the hardness values for an ever-growing proportion of isothermal transformation product, modified by the tempering which has occurred after precipitation (which varies according to when the precipitation took place), and of the hardness of a decreasing proportion of martensite and residual austenite representing the austenite which was present at the time of final quenching.

The results when considered in this way do not appear to indicate at all definitely that the isothermal product tempers like martensite. In fact the results could be explained by saying that the martensite formed on cooling had a hardness of 900 D.P.N., that there was some residual austenite present in the steels, and that the isothermal transformation product had an initial hardness of about 780 D.P.N. and tempered relatively slowly. The main difference between the isothermal product and martensite formed on cooling probably lies, as Dr. Pfeil has pointed out, in the detailed mechanism of formation, the isothermal transformation process being a normal nucleation and growth phenomenon, with growth occurring relatively slowly, whilst the martensite reaction on cooling presumably has an almost infinite growth rate, so that nucleation factors may completely control the progress of transformation.

Mr. **D. R. Thorneycroft** (The Mond Nickel Co., Ltd.): The authors have confined their attention to a group of plain carbon steels for which the **S** curves sweep to the right as the temperature falls towards M_s. The Institute's Atlas of Isothermal Transformation Diagrams† shows that for several alloy steels the **S** curves are upright or run back to the left in the neighbourhood of the M_s temperature. The last-named type of diagram is illustrated in Figure E for an En 40*B* 3% chromium–molybdenum steel which I have recently investigated.

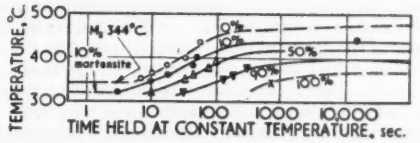


Fig. E—Progress of transformation above and below M_s temperature in sample of B.S. En 40B 3% chromium–molybdenum steel

In this steel, of which the M_s temperature was at 344° C., isothermal exposure at 320° C. produced results which I regard as exactly concordant with those observed above the M_s temperature in the intermediate range of transformation. At 320° C. transformation of the austenite to martensite on cooling had proceeded to 10% and isothermal transformation set in soon afterwards, as represented in Fig. E by the continuation of the 10% curve from above M_s. The isothermal decomposition of the remaining austenite progressed rapidly, so that the total transformation below M_s reached 50% on the 50% curve continued, and so on, in the manner indicated in the diagram. It will be noted that the direction of the curves for the three degrees of transformation is substantially unchanged at M_s. This continuity suggests that the nature of the isothermal transformation remains unaltered below M_s.

Throughout the course of isothermal transformation below the M_s temperature the etching characteristics and appearance of the reaction products were very similar to those of the highly acicular intermediate transformation products formed just above M_s. The similarity of tempered martensite structures and isothermal transformation products formed in the neighbourhood of M_s has been strikingly demonstrated by a series of electron micrographs published by the American Society for Testing Materials* and relating to a plain carbon steel of almost identical analysis with that of the authors' steel *A*. These electron micrographs merit close study by the authors, and should be compared with the structures of tempered martensite and isothermal transformation product shown by the light microscope.

In regard to graphical presentation of what happens below M_s the information provided in the inset diagram of Fig. 7 of the authors' second paper can readily be obtained from the well-established diagram of Payson and Klein, reproduced in Figure 6, and the authors' presentation does not seem to have any advantage in clarity. Moreover, the left-hand full line extending to the right below 175° C. in Fig. 7 is in fact the locus for the start of isothermal transformation plotted by Payson and Klein in their diagram.

CORRESPONDENCE

Mr. **G. R. Bish** and Professor **H. O'Neill** (University College, Swansea) wrote that in 1948 they commenced work on the effect of deformation upon the isothermal transformation of austenite. A special disc specimen carrying small projections of different heights was slipped from the austenitizing furnace into a salt bath, and then the projections were rapidly crushed, either at once or after a certain time, by means of a drop hammer. Transformation was allowed to proceed for predetermined times, after which the specimen was quenched and the variously deformed regions subjected to hardness exploration. The latter was carried out by means of a diamond ball according to the method of Meyer analysis. It was felt that the latter type of investigation might

* *Journal of Applied Physics*, 1949, vol. 20, p. 896.
† *The Iron and Steel Institute*, 1949, *Special Report No.* 40.

* First Progress Report of the Sub-Committee XI on Electron Microstructure of Steel (Preprint): 1950, *American Society for Testing Materials.*

provide useful information regarding transformation and transformation products, just as it had already done in the case of the age hardening of duralumin.* It is intended to publish the work in due course, but it may be said that series of structures have been obtained resembling those in Fig. 12 and having appropriate features corresponding with the different amounts of deformation.

The authors conclude that tensile deformation increases the rate of austenite transformation more than compression. Studies of deformation generally show that for equal stressing by tension and compression the former produces more hardening and potential energy than the latter, though the ratios would hardly be 2 : 1. One must also consider the effect of duration of stressing time upon the true stress in the metal. The initially applied 10 tons/sq. in. tension will lead to an increase of true stress by reduction of section of the austenite at M_s temperatures, whilst the increase of section under compression will lead to a decrease of true stress. On this basis there could be a difference in the results.

Given the possibility of different degrees of plastic deformation depending upon the two methods of stressing, there is also the question of the location of the material that has been examined microscopically in both cases. The tensile specimens appear to have been examined where the maximum reduction has taken place, but in the compressed steels there may have been the complication of barrelling and the possibility of a relatively smaller amount of strain at the area examined. The authors will probably agree that it is the amount of strain rather than of stress which matters. In support of the authors' findings Burgers† has reported that tension is more effective than compression during the transformation of zirconium.

Presupposing the elastic limit of the retained austenite near M_s to be 10 tons/sq. in.,‡ the lower the temperature in the bainitic regions the less should be the rate of acceleration of decomposition, since the difference between the elastic limit at $M_s + T°$, and at M_s becomes progressively less. This, indeed, is borne out in Fig. 19 by the convergence of the 100% decomposition lines for stressed and normal quench with decreasing temperature. According to Fig. 20 there is a divergence, so that the converse seems to be true in compression, and incidentally the normal quench and stressed-quench lines are in opposition to the data supplied in Table III. The stressed quench lines indicate—as reproduced—a deceleration of decomposition contrary to Table III.

In the discussion of results no mention is made of the observation that an applied tensile stress of 10 tons/sq. in. induces a randomly distributed transformation product similar to the normal quench. In the 20 tons/sq. in. compression test the transformation product lies on shear slip planes. Is this not significant ? Is it not possible that the tensile product is finer than the normal quench owing to the greater number of strain nuclei present in tension than in normal quench ? This would further illustrate the difference in distribution and type of strain nuclei following tension and compression. Would the authors consider the foregoing effects operative, to account for the differences in both types of applied stress, or alternatively that once plastic deformation sets in less strain nuclei are induced in compression than in tension ?

Lastly, with respect to the cone compression tests, the authors would seem to have overlooked the surface-area/mass ratio effect, the influence of which has actually been suggested by the authors themselves. As the ratio decreases the reaction rates will increase (*i.e.*, the isothermal transformation diagram will be moved to the left nearer zero time). This ratio will vary over the height of the cone when considering thin plate sections, and this should be borne in mind when studying the 200–50 tons/sq. in. cone compression test described.

* H. O'Neill, J. F. B. Jackson, and G. S. Farnham, *Philosophical Magazine*, 1933, vol. 16, p. 913.
† W. G. Burgers, *Physica*, 1934, vol. 1, p. 561.
‡ A. H. Cottrell, *Journal of The Iron and Steel Institute*, 1945, No. I, p. 93P.; also M. Cohen : *American Society for Metals*, 1949, vol. 41, p. 35.

AUTHORS' REPLY

Professor **F. C. Thompson** and Dr. **M. D. Jepson** wrote in reply : To deal adequately with all the points raised in the discussion would require an impossible amount of space, and we propose, therefore, to confine our attention to the main points. Dr. Pfeil raises the question of the nature of the strain required to accelerate transformation. Our experiments suggest most strongly that only when plastic deformation takes place is a measurable effect to be observed. In this connection, however, it should be remembered that the stress to which the austenite is really subjected is that externally applied, *plus or minus* the existing internal stress. The latter, due to the quenching operation, will increase as the temperature falls, and when the total stress on the material reaches the elastic limit, the M_s temperature is, in our opinion, reached. The influence of diffusion, as we have suggested, is bound up with the lattice strain which this process inevitably involves. An outstanding example of this is to be found in the grain refinement of a steel when it is normalized, the diffusion of the carbon resulting in marked distortion of the iron lattice. Such lattice strain may well be highly localized, and it should be remembered in connection with the whole effect of stress that microstrains may be just as important as macrostrains.

An aspect of the work, which does not appear to have received adequate consideration from those taking part in the discussion, is the progressive darkening of the transformation product with time. This is shown in some of the micrographs, but actual examination of the structure is necessary for its complete appreciation. In the lower temperature ranges the martensite is at first a light-etching constituent, which most clearly darkens in time.

If the idea of the initial isothermal formation of martensite is rejected, we may legitimately ask what would be regarded as the product formed when some quenched high-chromium steels are aged and transform at room temperature. Unless the first product is martensite, this constituent would appear to disappear entirely from metallography.

More than one speaker was unconvinced by curve 13 of the paper on the breakdown of austenite below the M_s temperature. We would point out in this connection that Payson and Klein* have already suggested a similar break, and that it is not in the least surprising that transformation curves, as normally obtained, do not show it. A fairly high degree of sensitivity in the experimental technique and observations made at small temperature intervals are required.

Mr. Mavrocordatos has suggested that our belief that there is a difference in the transformation product above and below the M_s temperature is an assumption that we have not attempted to prove. The experimental basis for our belief is perhaps best illustrated by Fig. 1 of the paper on the breakdown of austenite, in which, in the initial part of the curve, a totally different behaviour is to be observed above and below the M_s temperature. We have already mentioned that it is not surprising that

* P. Payson and J. L. Klein, *Transactions of the American Society for Metals*, 1943, vol. 31, p. 218.

the ordinary isothermal transformation curve does not show the break at the M_s temperature, but when he speaks of the " classical **S** curve " we must again reiterate our very strong belief that the **S** curve is the sum of two quite distinct effects, one due to changes during quenching, the other to isothermal transformation, and cannot, therefore, be used to consider either of these separately. We would point out, also, that the micrographic differences between the martensite in the second paper compared with the bainite of the earlier one are quite marked. From the beginning, the bainite needles etch to the same extent, whereas, as has already been mentioned, in the case of martensite a progressive darkening is easily to be observed.

Mr. Bucknall refers to the work of McReynolds, in which evidence is adduced that the M_s temperature is altered by stress. This work, although done on iron–nickel alloys, is in complete accord with our own. We would, however, point out that in our second paper only one steel *A* was used. His suggestion that martensite is produced by a process of normal nucleation and growth is not accepted by all other workers, and appears to us to be inconsistent with the cinematographic evidence ; further, it does not take into consideration the essential relationship of the martensite with the crystallographic structure of the austenite from which it develops.

Mr. Thorneycroft's remarks have, in the main, already been discussed in relation to the break which we believe to occur at the M_s temperature.

The authors look forward with interest to the publication of the work mentioned by Professor O'Neill and Mr. Bish. The points they raised are all pertinent, but do not, we think, require modification of our experimental evidence that, although both tensional and compressional strains accelerate transformation, this acceleration is greater when the stresses are tensional. We agree wholeheartedly with their final observations that the surface effect is significant, but, again, do not ourselves believe that this requires any essential modification of our conclusions.

Discussion on the Paper—

THE EFFECT OF COLD-WORK ON STEEL*

By J. H. Andrew, H. Lee, and others

Professor **J. H. Andrew** gave a short general introduction to the paper, and Dr. **H. Lee** (University of Sheffield) summarized its technical contents.

Mr. **H. H. Burton** (Vice-President) (English Steel Corporation, Ltd.) : This is indeed a monumental work, and I am sorry that my remarks will be confined to Section VI, because this Section deals with a subject with which I am more familiar than the effect of cold work in general.

In the first place the evidence that cold work decreases the rate of diffusion of hydrogen in steel and that it also enhances the saturation values is very important. If this work is to be pursued further, more experiments are needed to show whether or not the decrease in hydrogen diffusion occurs in both directions in relation to the grain flow of the steel. I believe it will be found that diffusion decreases in a direction transverse to the grain flow and increases in the longitudinal direction. Since it is obviously impossible to prepare a cylindrical specimen in which the grain flow in the whole of the wall is transverse, I think that it might be better to machine a cylindrical specimen out of a piece of plate so that in one direction, as indicated in Fig. F, you would obtain an effect similar to that reported by the authors, whilst in a direction at right angles you would get penetration of the hydrogen in a direction corresponding to longitudinal grain flow. With such a test piece it might be that the total effect of cold work would be found to be small, the effect in one direction being more or less cancelled out by the other.

Some of us who have made a number of chemical-reaction vessels know that if a cover for the end of such a vessel is to be as little permeable to hydrogen as possible, the grain flow should be arranged so that it is parallel to the underside of the cover. Examination of samples which have been in service for some time has shown that complete decarburization by hydrogen may be encountered up to a considerable depth and that this depth is much greater in the direction of the grain flow than at right angles to it. The former condition exists in the bore of the hole which is generally made through the cover, whilst the latter condition exists on the bottom face of the cover itself, where the area exposed to hydrogen may be much greater. The question that arises is whether there is any difference in the effects of hot and cold work respectively, assuming that both produce a similar amount of directional grain flow. Linked up with this and mentioned on page 384 of the paper, just below Table II, is the suggestion that " the observed decrease in the rate of hydrogen diffusion in cold-worked iron specimens is partly due to the occlusion of molecular layers of hydrogen at mosaic boundaries or disjunctions." I wonder how far the authors have explored the possibility of the hydrogen, no doubt in the molecular form, being associated with non-metallic inclusions. Some work is going on in other directions at the moment which seems to indicate that even hot rolling may leave little voids at the tail ends of silicate inclusions in particular, and it seems to me that hydrogen might conceivably be occluded at such places. In this same connection I think it may be important to note that, where the familiar fish-eye fracture occurs in a piece of hot-worked steel subsequently heat-treated in some suitable way, the fish-eye, in my experience, is always focused on a small inclusion, and there is some reason to believe that even large hairline cracks usually have inclusions near their point of origin.

On page 385 the authors deal with the formation of

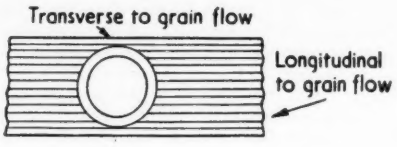


Fig. F—Machined cylindrical specimen

* *Journal of The Iron and Steel Institute*, 1950, vol. 165, June, pp. 145–184 (Sections I and II) ; Aug., pp. 369–395 (Sections III–VII).

hairline cracks in relation to the cracks illustrated in Fig. 66 and suggest that the apparent similarity "may help to dispel the view so often expressed that the formation of hairline cracks in steel must necessarily be associated with thermal transformations." My own view is that the cracks shown in Fig. 66 would be more properly described as 'pickling cracks' and are in fact quite different from true hairline cracks. Generally speaking, they are accompanied by intergranular fractures, whereas most hairline cracks are not intergranular. It may be that some further clarification is necessary, because the view held by many of us concerning thermal transformations is not so much that the transformations themselves cause hairline cracks but that the stresses set up through these transformations, if not relieved by some means, may be the cause of hairline cracks when associated with embrittlement due to hydrogen. In the case of the cold-worked steel, no doubt stresses of a sufficient order are caused by the cold work itself, but the conditions of formation of the two types of crack seem to be entirely different.

Dr. Lee, in presenting the paper, mentioned that hydrogen diffusion appears to decrease as the hardness of the metal increases. In connection with Table VII in this Section of the paper, I cannot help wondering whether it is justifiable to attribute the difference in diffusion rates entirely to chromium, bearing in mind that the V.P.N. hardness figures are respectively 245 and 302. It seems possible that the difference in hardness resulting from difference in microstructure may play an almost equally important part. Against my argument is the evidence in Table V, where material which has been isothermally treated at 480° C. shows a higher rate of diffusion than that of steel normalized from 850° C., which appears to indicate an effect primarily due to microstructure rather than to hardness. It seems possible that the structural differences are really very important in this respect and I wonder whether the authors have determined the hydrogen diffusion in specimens which were isothermally transformed in the pearlite range, as distinct from the intermediate range?

Dr. **R. H. Greaves** (London): The Section which interested me particularly was that which dealt with dimensional changes. The results in that Section have many applications, for instance in the behaviour of springs made from cold-worked materials, and especially springs which have to be exposed to elevated temperatures. The one which I thought of particularly, however, was the strengthening of cylinders by wire winding, because this is a subject with which I was concerned many years ago in connection with the now abandoned method of wire-winding gun tubes.

The object of the work at that time was to obtain a gun wire in a condition in which it would withstand the heating which it received during the building or firing of the gun without any loss of tension. A 0·7% carbon steel in the cold-drawn condition, with a tensile stress of something over 100 tons/sq. in., might in those circumstances lose more than half its tension owing to permanent increase in length of the wire on heating, the increase in length which was pointed out by the authors, but if the wire were given a preliminary heating before being wound on to the tube the loss in tension was very much less. A cold-drawn alloy-steel wire—a chromium–vanadium or chromium–molybdenum steel wire—also lost a similar large percentage of its tension when heated to 200° C. if wound in the cold-drawn condition, but if preheated to a temperature such as 400° C. before winding the loss of tension in subsequent heating was very small.

In actual winding trials on cylinders of about 6 in. internal diameter and 1½ in. wall thickness, wire wound at about 45 tons/sq. in. tension, the loss of tension of the wire was:

Steel	Initial Treatment, °C.	Loss of Tension on Heating At 200° C.	At 300° C.
C	200	21%	58%
Cr–V	400	10%	24%
Cr–Mo	400	6%	20%
16/10 Cr–Ni	500	Nil	10%

These figures, in each case the average of about five tests, were obtained from measurements of changes in the internal diameter of the tubes. It is clear that the preheating should be at as high a temperature as is consistent with retaining adequate yield strength in the wire, and it is in this respect that the alloy-steel wires have an advantage. All these wires showed an increase in density during the pretreatment. In the carbon, chromium–vanadium, and chromium–molybdenum steel wires the increase in density was accompanied by an increase in length; in the austenitic steel it was accompanied by a decrease in length, and this probably assisted in maintaining the tension in the wire when subjected under stress to the high temperature. The decrease in length of the austenitic steel was, however, only three-fifths of what would be expected if the contraction had been uniform in all directions. This increase in length—or in the austenitic steel the insufficient decrease in length—is accounted for by the directional effect of cold drawing. X-ray examination showed marked directionality in all these wires both before and after treatment, but no austenite, except, of course, in the austenitic steel.

I am glad that the authors have abandoned the suggestion that these properties are associated with austenite formation. Austenite is formed under impact stresses, as shown in Fig. 50 in the paper; that is familiar to anyone who has examined fired armour-piercing projectiles and armour. Under abnormal conditions austenite may be formed in carbon-steel wire, but it quickly changes to martensite and generally leads to fracture.

I do not propose to discuss the mechanism of the change in dimensions put forward by the authors, but I think that they are quite right in seeking the explanation along the lines of directional lattice distortion.

Mr. **F. R. N. Nabarro** (Birmingham University) (read in his absence by Dr. T. Ko): I should like to draw attention to two points. The first is the increased rate of work-hardening and the decreased rate of fall of the density observed in high-carbon steels when the reduction in area exceeds about 40%. Does this mean that a new mechanism of deformation sets in when this strain is reached? In the first place we may note that an inflection in the plot of hardness against reduction in area is not itself significant. The strain as the reduction increases from 10% to 20% is very much less than the strain as the reduction increases from 80% to 90%. During the latter process the wire doubles its length, and it is not surprising that there is a large increase in hardness. The true indication that a new mechanism of deformation is setting in is provided by an irregularity in the plot of hardness against the logarithm of the original area divided by the present area. If the most striking curves, those for steels *D*1 and *F*1 in Fig. 1*a*, and steel *E*1 in Fig. 1*c*, are plotted in this way against the logarithmic strain the inflections become less obvious, and the evidence for a new mode of deformation is much less convincing. However, by the same process the sudden inflection of the dilatation curve (curve 2 in Fig. 12) towards the horizontal is made even more pronounced, so that the existence of some change at about 40% reduction seems well established.

I can offer no clear theoretical explanation. Some increase in the rate of hardening at large reductions is to be expected because the average reduction in each draft was approximately a constant fraction of the original area, and not a constant fraction of the present area. Would it be possible to do a similar experiment with the same 'true' strain at each draft? Even if this were done the flow lines in successive drafts might not remain similar, since the variation of strength with distance from the axis changes in successive drafts. Again, the change in the die angle must affect the hydrostatic pressure in the deforming metal, and so alter the likelihood that minute cracks would open or close during drawing. The observed reduction of density by 0·27% corresponds to a rise in temperature of 75° C., whereas the greatest amount of energy which has been observed to be stored in a cold-worked (mild) steel* would have raised its temperature by less than 13° C. It is thus reasonable to believe that the cold-worked structure does contain holes, where the word 'hole' implies a region so large that atoms on opposite sides of it attract one another with a force much smaller than the maximum force between two atoms.

The second point I wish to make concerns the suggestion on page 391 that "it is the cementite which must undergo an amount of plastic yielding sufficient to allow the ferrite to recover elastically." It seems to me that one need not draw this unwelcome conclusion from the observations. Imagine a sheet of ferrite lying between two rigid parallel sheets of cementite, the ferrite being, in accordance with the X-ray evidence, in compression in its plane and in tension perpendicular to its plane. If we regard this strain as being produced by an elastic hoop bound round the edge of the sheet of ferrite, flow in the ferrite will make the sheet of ferrite even smaller and thicker, as Andrew and Lee suggest. It is more reasonable to regard the rim of the sheet of ferrite as being free, and the strain as being produced by shearing stresses across the interfaces between the sheet of ferrite and the sheets of cementite; I have in mind a distribution of stress of a kind similar to that which might arise from their differential contraction on cooling. These shearing stresses are greatest near the outer edge of each surface of contact and fall to zero at the middle of each surface. When the temperature is raised, flow first begins in the regions of high shearing stress at the edges, and the disc of ferrite breaks away at the edges and projects outside the discs of cementite. This, in a fibre structure, gives rise to the observed longitudinal dilatation.

Mr. **A. G. Hock** (Workington Iron and Steel Co.): I wish to raise three points, namely:

(1) Has the work of the authors shown evidence upon the connection between the rate of work-hardening in cold working and one of the main features of the Brinell test, *i.e.*, the probable reduction of the depth and diameter of the impression of the ball because the steel hardens under flow? The speculation may be that the rate of work-hardening of steel is roughly sufficient to allow a consistent proportionality between hardness number and breaking stress, provided that we take an area greater than that of the projection of the impression. An appreciable change in the work-hardening rate might thus be noticeable in making Brinell impressions and, if so, this may be linked eventually with the case of other metals where a similar relation between hardness and strength is not found.

(2) Have the authors made particular observations on the angle at which their specimens fractured? Whilst this may be mentioned as 45° it is not usual to find values of the order of 50°. Cognate to this small point is the difficulty which arises in attempting to take up quantitatively the suggestion that the strain is divided between cementite and ferrite. This may be a useful hypothesis but might it not become quite inapplicable in the extreme case of say a diamond embedded in a mass of lead extruded through a die?

(3) The experiments on hydrogen diffusion reported in this and earlier papers by the authors have included a very convenient set-up in the form of an electrolytic cell in which a suitably high pressure of atomic hydrogen can be developed easily. The authors will have found that the measurement of the rate of flow of hydrogen through the walls of their hollow specimens shows that the surface of the specimens exhibits properties which vary, not unexpectedly, with the method of preparation and with the time of the electrolysis.

The rate of flow and the surface concentration are higher when hydrogen ions are collected directly at the electrode. Much smaller flow occurs, for instance, when hydrogen is produced by secondary reaction in alkaline solution, and one concludes therefore that either a continuous preparation of the surface or its satisfactory protection during the electrolysis will be required before results of a quantitative nature can be obtained. The author's findings on this point and details of steps taken to overcome the difficulties would be appreciated very much.

Dr. **B. Matuschka** (Leoben-Donawitz, Austria): Have the authors done any work on the effects of small traces of other elements, such as copper, nickel, chromium, and so on? Nowadays when working with war scrap it is impossible to avoid small traces of these elements, and it has been our experience that if the carbon content is a little higher, about 0·4, 0·5, or 0·6%, for wires, then the cold-rolling and cold-drawing behaviour will be very much changed by these small traces of other elements. We had to change our practice and use only clean scrap for steel production.

The **Chairman** (Mr. James Mitchell, C.B.E., Hon. Treasurer) (Stewarts and Lloyds, Ltd.): I should like to ask why, having embarked on an investigation on cold work, the authors ignore the fact that the element nitrogen exists. It is not given in their table of analyses. The profound effect of the nitrogen content on cold-working properties is well known, and it would be better, if only for the purposes of the record, that the amount of this element present in the steels used should be shown.

AUTHORS' REPLY

Dr. **H. Lee** (in reply) said: We do not claim that the work, either on cold work or on hairline cracks, has reached anything like finality. Mr. Burton suggests that in the case of cold-drawn wire we might increase the diffusion in one direction and decrease it in the other. That is certainly the case in steel, as we have pointed out. Our implication is that if the steel is cold-drawn into a fibrous structure, the rate of hydrogen diffusion in the cross-sectional direction would be less than in the longitudinal, because we assume that the rate of hydrogen diffusion in cementite is less than in ferrite.

There is a possibility that, in regard to iron, the rate of hydrogen diffusion may vary with the crystallographic direction, because, as is well known, diffusion is related to

$$D = Ae^{-\frac{Q}{RT}}.$$

In comparing the diffusion in different directions, one would expect a small difference, but how much we are

* G. I. Taylor and H. Quinney, *Proceedings of the Royal Society*, 1934, series A, vol. 143, p. 307.

XUM

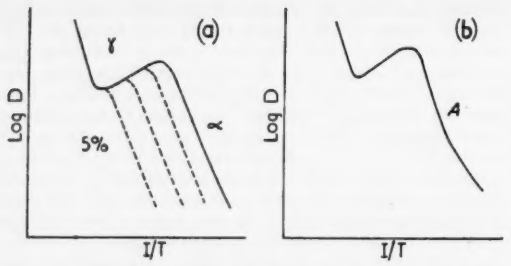


Fig. G—Diagrammatic plots of log *D* against *I*/*T* for (*a*) chromium and iron, (*b*) iron

not prepared to say. On that point, therefore, we agree with Mr. Burton. We also agree that occlusion of hydrogen could be associated with inclusions as demonstrated by American workers who have dealt with fish-eyes.

In regard to the large cracks shown in Section VI, p. 385, Mr. Burton says they are not hairline cracks. This is a controversy about terms ; if we use the name ' hairline cracks ' only for those cracks which occur in steel in the forged or rolled conditions, I agree that these were not hairline cracks. But we have used the term in a wider sense ; we call any internal cracks caused by hydrogen ' hairline cracks,' so that it is merely a difference of opinion on terminology.

At the end of Section VI we said, on the basis of a few experimental results, that the chromium has an effect in slowing down the rate of hydrogen diffusion. That statement is subject to criticism, and Mr. Burton questioned whether it had anything to do with the hardness. Fortunately, this hydrogen diffusion work has been continued by one of our colleagues, who found that, taking chromium and iron without the presence of carbon, and plotting log D against I/T, then as chromium is added to iron the γ region is little affected, but in the α region the curve progressively comes down as the amount of chromium increases (*see* Fig. G*a*). With 5% chromium in the α range the chromium could decrease the rate of diffusion by as much as 1000%. On the results of that latter work, I am happy to say that, although our conclusions in the present paper are somewhat speculative, the speculations have " come off."

Referring to the effect of hardness, if chromium is added to iron the hardness is increased, and the same happens if nickel or molybdenum are added. Our colleague found that nickel has very little effect on hydrogen diffusion in α iron, and the same is true of molybdenum. Those results confirm, I think, our statement that chromium, not hardness, is the cause.

We are fully aware of the valuable work that Dr. Greaves published in 1924, and we are glad to find that his experience and ours are in full accord. The difference between his austenitic Ni–Cr steel and the others is obvious, because with austenitic steel there is no free cementite.

Mr. Nabarro mentions that if a log plot is adopted it makes the kink less pronounced in the hardness curve but more pronounced in the density curve. We should like to ask him whether he has considered a curve in which the rise is very pronounced. We think that the X-ray results would be even more significant than the hardness curves, because hardness is a property, especially in steel, which can be influenced by many other factors.

We are indebted to Mr. Nabarro for mentioning that the cementite need not deform to allow the ferrite to recover elastically. We should say, however, that to look at one result is not sufficient ; account must be taken of all the results in the paper as a whole. We think he will agree that there is good evidence in the paper to show that the strain does exist in cementite. Perhaps he will tell us how the initial strain in cementite is recovered on heating.

We agree with Mr. Hock that fracture takes place at 51° and not at 45° ; we used the 45° to distinguish it from the vertical fracture, and did not make an accurate measurement. If he thinks it is 51° due to friction, that seems a good reason for believing that it is so.

Referring to the division of the strain between cementite and ferrite, Mr. Hock says that it is possible to harden a structure completely unstrained. We have shown that in steel, where there is ferrite and cementite, strain exists in both.

His point about hydrogen diffusion is very interesting. Our experience is that it is not possible to achieve a clean surface for any length of time, and in any case it varies from one specimen to another. We tried to control it, but we did not know how to do so. We agree that it may be a question of surface reaction. Without using electrolytic methods, Dr. Chang has worked on hydrogen diffusion at elevated temperatures down to about 150° C. If log D is plotted against I/T for iron (*see* Fig. G*b*), the straight-line portion marked A only exists to about 400° C. If the specimen is treated in the α range, the diffusion follows that curve, but if it is heat-treated above that range it can come either below or above. He found that at high temperatures, say 500° C. or above, the hydrogen diffusion measured in that way is proportional to $p^{\frac{1}{2}}$. That is to be expected from Dr. Richardson's calculations. When the temperature falls below 400° C. he found that it was no longer proportional to $p^{\frac{1}{2}}$, but proportional to p^x, where x is greater than $\frac{1}{2}$. For example, at a temperature of 500° C. x is roughly equal to 0·5, but at 400° C. x may be 0·55, and at 300° C. it may be 0·65, and so on, so that at 200° C. it could be as much as 0·8 or more. Unfortunately, 200° C. is the lowest temperature to which it is practicable to go.

Two possibilities result from that. Molecular hydrogen can diffuse below zero, but we do not think that molecular hydrogen can diffuse through steel ; we think that what occurs is due to surface reaction. As the temperature is low, surface reaction becomes more and more important, but we do not know its real mechanism.

In reply to Dr. Matuschka we must admit that we have not investigated the effect of small traces of other elements, such as copper and nickel, on plain carbon steels, in regard to the cold-working properties.

The Chairman asked whether we had examined the effect of nitrogen in steel. We did examine the effect of nitrogen, especially in regard to the 0·58% carbon steel, where the nitrogen was of the order of 0·2%. What effect that had on other properties we cannot say, unless the Chairman has any particular properties in mind.

Discussion on the

ATLAS OF ISOTHERMAL TRANSFORMATION DIAGRAMS OF B.S. EN STEELS*

Submitted by the British Iron and Steel Research Association, Metallurgy (General) Division, Thermal Treatment Sub-Committee

Dr. **L. B. Pfeil** (The Mond Nickel Co., Ltd.) (Chairman of the Isothermal Transformation Group) presented the "Atlas of Isothermal Transformation Diagrams of B.S. En Steels."

Dr. **N. P. Allen** (National Physical Laboratory) : The Introduction to this Report provides ample evidence of the care with which the work has been done. It might have been feared that the expedient of drawing the steels down to wire, which was adopted to avoid possible errors owing to segregation, would cause the steels to transform in an unusual manner. The smallness of the change of transformation behaviour actually observed is reassuring, and is interesting theoretically because of the marked refinement of the microstructure. Did this refinement persist throughout the heat-treatments involved in the determination of the isothermal transformation diagram ? This might have a bearing on the extent to which grain and specimen size control transformation rate.

The Sub-Committee have given some account of the way in which the diagrams should be used. I am glad they have avoided describing elaborate calculations for predicting the behaviour of steels under specified conditions of cooling, as such calculations, unless made with the utmost circumspection, are likely to be more misleading than helpful. Steels are not yet so well understood that their transformation rates can be controlled within narrow proportions, and these diagrams are best used qualitatively with an ample appreciation of the possible margins of error. In that matter I fully agree with what Dr. Pfeil had to say in presenting the Report.

The Introduction lays proper stress on the importance of the prior condition of the steel and of austenitizing conditions. In addition, the composition range of the En steels referred to is commonly so wide that steels of very different transformation characteristics can be included in one specification. In these circumstances, the Sub-Committee must have had difficulty in ensuring that each of their chosen steels was typical of its kind, but they think they have been successful, and it will be of interest to see whether others agree with them. They have relied partly on the supplier's assurance that the sample was typical, partly upon comparisons with the steels reported upon in the Hardenability Symposium,† and partly upon occasional checks which are described in the Comments. These Comments contain a great deal of useful information, and they are a very valuable part of the book.

I notice that one of the steels (No. 19) was rather lower in hardenability than would be expected of its kind. Different steelmakers are in the habit of leaning to one side or the other of the range permitted in the specifications, and this steel may have been supplied by a maker who liked his chromium–molybdenum steels to be rather soft. The Atlas will serve a useful purpose if it induces steelmakers to supply materials that are not too far removed from the expected standard of hardenability, for heat-treaters have much to gain from reliability of performance in this respect.

It will be remembered that the En steels were originally designed to avoid unnecessary multiplication of types of steel. The diagrams enable one to judge how far this objective has been achieved. They display on the whole an astonishing variety of characteristics, but there are some cases where the diagrams are sufficiently alike to raise the question whether both types of steel are really required. Examples are En 23, 24, and 100, and En 17 and 110. Whether one or other of them could be dispensed with really depends on whether equality of hardening characteristics also means equality of mechanical properties. That question is often raised, but to my mind it has never been fully answered. One of our Committees might be well advised to address itself to this matter.

The present series of steels was developed at the beginning of a rearmament programme, preceding the last war, and we are now at the beginning of another rearmament programme. It is most important in the national interest that we should enter this programme not only with the best, but also with the most economical, series of steels that can be devised. Are the steels described in this book the most economical that can be devised ? During the last war both our friends and our enemies noted that we in this country were more free in the use of alloying elements than other people. Here we have, for example, eight samples of nickel–chromium and nickel–chromium–molybdenum steels, and only two samples of chromium–molybdenum steels upon which the Germans relied very successfully during the last war. Are the chromium–molybdenum steels being neglected ? The manganese–chromium steels form another series, which has been looked at frequently and discarded for one reason or another. Is it not possible that recent advances in metallurgy enable us to re-examine this series and obtain better results than could be obtained before ? These are important questions and we ought to tackle them seriously.

Dr. **W. Steven** (The Mond Nickel Co., Ltd.) : The isothermal diagrams of a second series of B.S. En steels very similar to that dealt with in the Atlas have been determined in the laboratory of The Mond Nickel Company, and it was of interest to compare the two sets to gain some indication of the variation to be expected between the transformation characteristics of different casts of the same type of steel. Briefly, although many of the diagrams were closely similar, the comparison revealed instances of two to threefold, and occasionally greater, differences between the respective incubation periods and reaction times in both the pearlitic and the bainitic transformation ranges. The compositions of the steels studied were by no means

† *The Iron and Steel Institute*, 1946, *Special Report No.* 36.

* *The Iron and Steel Institute*, 1949, *Special Report No.* 40.

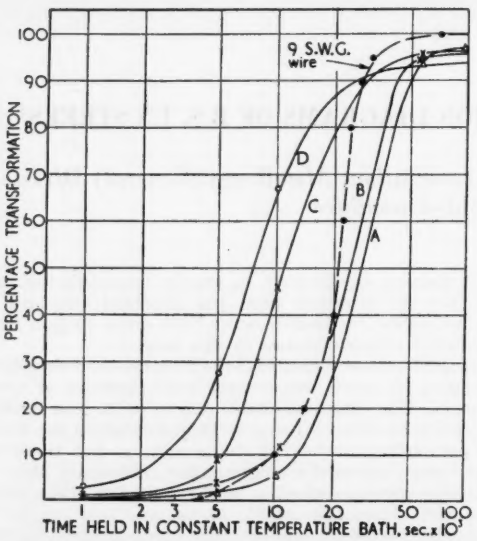


Fig. H—Reaction curves of samples from four positions in the cross-section of a 4-in. sq. billet of En 23 steel. Curve *A*, surface position; curve *B*, 0·5 in. from surface; curve *C*, 1·0 in. from surface; curve *D*, axial position. Austenitizing temperature 835° C. Transformation temperature 600° C.

representative of the extremes theoretically possible, and one might therefore expect greater variations than those observed. On the other hand, the extent of the variations actually encountered will probably be restricted to some extent by the mechanical properties required by specifications.

Some information has also been obtained on the variations of transformation characteristics likely to be encountered within a given cast of steel, or more particularly the variations occurring across the sections of billets. The full lines in Fig. H represent the reaction curves for samples taken from different positions across the section of a 4 in. sq. billet of B.S. En 23 steel transformed at 600° C. Obviously the transformation characteristics vary significantly across the section of the billet, and in this particular billet the centre transformed most rapidly, that is to say had the lowest hardenability. The broken line represents the reaction curve for 9-gauge wire rolled and drawn from the full cross-section of the same billet. The billet samples had shorter incubation periods and longer reaction times than the wire samples. These differences are in accordance with the hypothesis that the variations across the billet, and the discrepancies between the reaction curves of billet and wire samples, are due to varying degrees of micro-segregation. Similar variations of transformation characteristics have been observed in billets of other types of steel and, indeed they have occasionally been noted to persist even when the steel was drawn to wire. It is apparent therefore, as indeed has been emphasized in the Introduction to this Report, that a generous safety factor must be applied to any heat-treatment time derived from a consideration of isothermal transformation diagrams, not only to allow for differences in average chemical composition, but also to allow for variations of transformation characteristics within bars and billets.

It is hoped that in the course of their future work the Transformation Group will find it possible to make a more detailed study of the martensite reaction. More precise knowledge of the progress of this reaction with temperature, particularly during its later stages, would greatly assist the assessment of the factors influencing the retention of austenite and the occurrence of quench-cracking.

Finally, I would suggest that a valuable future addition to this Atlas would be a set of 'continuous cooling' diagrams, determined on the same series of steels by the method outlined by Liedholm,* or if possible by some improved method. Such diagrams, although possibly of less fundamental value than isothermal diagrams, would help to bridge the gap between the somewhat artificial conditions under which the latter are determined and the conditions encountered in day-to-day heat-treatment.

Mr. **C. L. M. Cottrell** (British Welding Research Association): One rather special use of this Atlas is in connection with the metallic arc welding of high-tensile steels, during which the fast cooling rates occurring in the heat-affected zone adjacent to the weld cause considerable hardening of this zone. Excessive hardening is generally associated with hard-zone cracking, which is the major problem in welding alloy steels.

At the British Welding Research Association we have made considerable use of the Atlas of isothermal transformation diagrams for determining the welding procedure necessary to prevent, as far as possible, the production of martensite during transformation of the heat-affected zone. In this use of the isothermal transformation diagrams there is only a slight displacement of the curves downwards and to the right with conditions

* *Transactions of the American Society for Metals*, 1947, vol. 38, pp. 180–208.

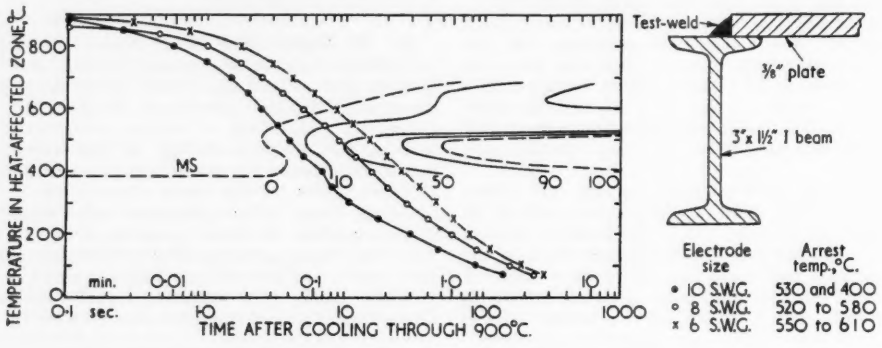


Fig. I—Cooling curves for structural joint

Fig. J—Austenitized 1150° C.

Fig. K—Austenitized 900° C.

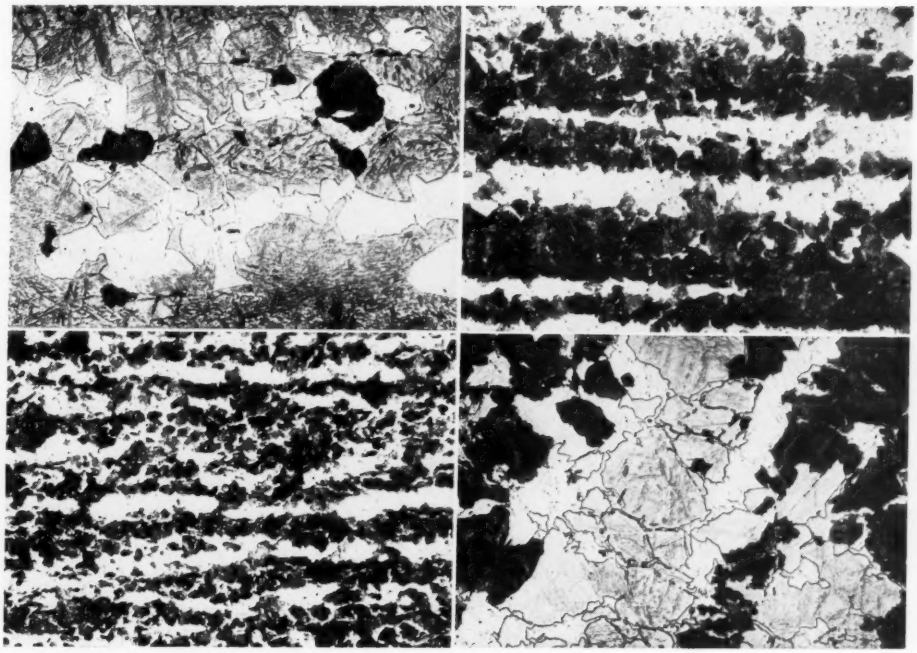


Fig. L—Austenitized 1150° C. Forged to 900° C. (surface temperature)

Fig. M—Austenitized 1150° C. Forged to 900° C.

Figs. J to M—B.S. En 17 steel specimens isothermally treated 640° C. ; 5 hr. × 150

[*Discussion on Special Report No.* 40
[*To face p.* 138

of continuous cooling, a fact which has been shown by Grange and Kiefer.*

In welding high-tensile steel the cooling may be delayed by means of preheat, postheat, or increased energy input to the weld (*i.e.*, larger fillet size) in order to reduce the amount of martensite formed. In Fig. I a typical structural joint is shown and three cooling curves have been plotted for a point in the heat-affected zone of fillet welds on this joint, made with 10, 8, and 6 S.W.G. electrodes and consequent different fillet sizes. These cooling curves, which were observed with a steel of slightly lower alloy content than steel En 13, are superimposed on the isothermal transformation diagram. The slight difference in alloy content is seen partially to offset the change in position of the diagram due to continuous cooling conditions. The arrests in the cooling curves are very close to the expected positions. In this instance the 10 S.W.G. weld, which showed an arrest at the M_s temperature as well as an intermediate transformation, gave hard-zone cracking. The other two welds, made with 6 and 8 S.W.G. electrodes, did not show any arrest at the M_s temperature and gave no hard-zone cracking. This indicates that there is sufficient ground for using the isothermal transformation diagrams to determine satisfactory procedures for welding alloy steel, provided that corrections are made for any change in steel composition and for continuous cooling conditions.

Mr. **H. Allsop** (Brown Bayley's Steel Works, Ltd.): It seems very probable that one of the most useful practical applications of isothermal transformation data for alloy structural steels will be in connection with treatments for the controlled cooling of forgings or other products from hot-working temperatures. Some form of delayed cooling is customarily applied to alloy structural steels to prevent air-hardening—with its attendant risks—and also to suppress internal cracking due to other causes. Such ' caretaker ' treatment would appear to be most advantageously carried out by ensuring that the steels are transformed by isothermal treatment in the pearlitic range. In some instances—for instance B.S. En 28 and 30—transformation in the pearlitic range may be impracticable, but in most cases a close approach to the desired effect appears to be obtainable in a reasonable time, which may well be less than the time taken up by, and moreover with greater efficiency and regularity than, some of the less systematic methods at present in use.

It is known that the time required for transformation is influenced by the prior austenite grain size and that increase in austenite grain size increases the time required for complete transformation. The Atlas diagrams have all been constructed from data obtained from samples heated to temperatures approximating to the normal hardening temperatures for the respective steels, which are, of course, considerably lower than the initial hot-working temperatures, for which reason it is unlikely that a hot-worked article will conform to the appropriate diagram if isothermally transformed during cooling.

A few preliminary tests have been made on steels conforming to B.S. En 17 and En 56, to indicate the effect on the transformation time of varying austenitic grain size and also the refining effect of hot-working on the austenitic grain size resulting from heating to a forging temperature. The steels employed do not differ materially from those used for the determinations of the type diagrams in the Atlas. The samples were cylinders all of the same size (2 in. long by $1\frac{3}{8}$ in. diameter), were heated to the appropriate temperature, and hot-worked samples were hammered on the end ; the lower end was placed on a warm anvil to prevent undue chilling. The temperature during working was observed by an optical pyrometer, but it was noted in all cases that the corners, particularly at the upper end, were cooler than the body of the pieces. The unworked samples and the hammered ones after completion of working were quenched in a salt bath at the transformation temperature and finally water-quenched. The results for B.S. En 17 (Atlas data : Transformation complete at 650° C. in 5 hr. ; hardness 189 D.P.N. Sample analysis, C 0·37%, Si 0·28%, Mn 1·60%, Cr 0·04%, Ni 0·09%, Mo 0·45%. Transformation temperature 640–650° C. ; 5 hr.) are summarized in Table A, and photomicrographs of the structures of specimens *a*, *b*, *c*, and *d* are reproduced in Figs. J to M, respectively. It will be seen that the structures of specimens *b* and *c* are practically identical, and that *d* is considerably coarser.

Data for B.S. En 56 (Atlas data : Transformation complete at 700° C. in 15 min. ; hardness 202 D.P.N. Sample analysis, C 0·25%, Si 0·43%, Mn 0·37%, Cr 13·9%, Ni 0·48%. Transformation temperature, 675–700° C. ; 30 min.) are presented in Table B ; since neither specimens *g* nor *h* had completely transformed in 30 min., the test was repeated with the transformation time increased to 1 hr. The results are shown in Table C.

The results indicate the effect of varying austenitizing temperature, but they also show that the response of these materials to transformation is markedly influenced by the temperature at which hot-working is completed, that influence being due to the austenitic grain size induced thereby, so that substantially the same result is obtained whether the material be austenitized at a particular temperature or at a higher temperature but worked down to the same lower temperature. It is unlikely that hot-worked parts will be finished at a uniform temperature ; for example, from the same initial heat, bars are likely to be finished colder than drop or other machine forgings of comparable section, and larger forgings in particular are not likely to be of uniform temperature either on the surface or from outside to centre ; comparison of the results obtained from the forged samples, notably of En 17, shows that the variation in finish forging temperature can have an appreciable effect on the structure and hardness resulting from the

* *Transactions of the American Society for Metals*, 1941, vol. 29, pp. 85–116.

Table A

SUMMARY OF DATA FOR B.S. EN 17 STEEL

Specimen	Austenitizing Temp., ° C.	Finish Forging Temp., ° C.	Hardness, D.P.N.	Microstructure
a	1150	...	420–440	Approx. 75% martensite. Isolated grains fine pearlite. Some ferrite. *See* Fig. J
b	900	...	200–210	Completely transformed to fine pearlite. *See* Fig. K
c	1150	900*	220–230	Completely transformed to fine pearlite. *See* Fig. L
d	1150	>900†	250–400	Approx. 50% martensite. Fine pearlite and ferrite. *See* Fig. M

* Outer edge † Interior

XUM

Table B

SUMMARY OF DATA FOR B.S. EN 56 STEEL

Specimen	Austenitizing Temp., ° C.	Finish Forging Temp., ° C.	Hardness, D.P.N.	Microstructure
e	1150	...	490–520	Slight transformation on grain boundary
f	980	...	220–230	Completely transformed
g	1150	980*	270–285	Considerable transformation on grain boundaries. Fine grain
h	1150	>980†	360–390	Partial transformation on grain boundaries

* Outer edge † Interior

same isothermal treatment. This observation, taken in conjunction with the points mentioned on page 14 of Special Report No. 40, indicates that the diagram therein will not adequately represent the response of hot-worked steel, even in small sections, to isothermal treatment.

It is suggested, however, that more relevant data for the treatments envisaged could be obtained by observing the progress of transformation from the highest austenitizing temperature likely to be used in forging practice. This would adequately take care of the possible variables mentioned above, and only the pearlitic temperature range need be studied. Such data, it is believed, would have considerable practical value in dealing with numerous hot-rolled and forged items of moderate mass. Where the masses involved are very great it is probable that no isothermal data are really applicable.

Mr. **C. C. Hodgson** (Leyland Motors, Ltd.) : The isothermal diagram adopted in the Report as typical of En 21 steel differs considerably from others for similar steels published elsewhere. Molybdenum is known to have a marked effect in retarding the transformation of nickel steel. What was the molybdenum content of the En 21 steel used ?

In connection with the use of wire for test specimens, no doubt this was the correct procedure, but it would have been better had it been possible to use as supporting evidence results obtained on steels reported on in the Atlas rather than two that are not there, namely En 22 and En 27.

The Sub-Committee appears to deprecate the use of their diagrams in the designing of heat-treatment schedules. Perhaps these ideal diagrams based on ideal compositions would not be very useful for that purpose, but nevertheless one feels that isothermal diagrams could provide an excellent basis on which heat-treatment schedules should be planned, particularly for the newer treatments—isothermal annealing, austempering, and martempering. For such work, however, diagrams representing the extremes likely to be met with in any specification would appear to be necessary, rather than one diagram based on an ideal composition.

The use of isothermal annealing and martempering will probably extend in future, particularly for case-hardening steels and case-hardened components. In this respect it is unfortunate that the Sub-Committee were not able to include case-hardening steels in their programme, and one would like to feel that it will be possible for this omission to be remedied. If that is done, high-carbon steels (representing the case of a carburized component) as well as low-carbon steels should be used ; also, particular attention should be paid to residual elements. Some time since, in an essentially practical and limited investigation on the isothermal annealing of En 36 and En 39A, it was found that, whilst this was distinctly attractive when using steels free from molybdenum or containing not more than a few hundredths of one per cent. of that element, it was not possible to adopt such a method in works practice because of the disturbing effect of relatively large variations in the residual molybdenum from cast to cast.

Mr. **E. Johnson** (William Jessop and Sons, Ltd.) : The diagrams in the Atlas have been plotted by what is now the conventional method, but there are others which are sometimes used. French, and occasionally Russian, workers have plotted the data obtained using isochronous curves. Delbart describes the use of three-dimensional models with the amount of transformation on a vertical axis perpendicular to the temperature and time axes. I have made a number of such models in plasticine, and reference to these forcibly illustrates the pitfalls to be avoided during the isothermal annealing of steels like En 25. A diagram of a model of this type

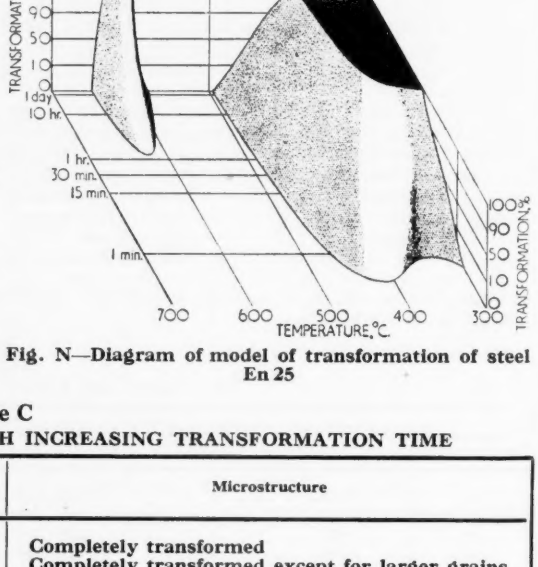


Fig. N—Diagram of model of transformation of steel En 25

Table C

REPEAT TESTS ON B.S. EN 56 STEEL WITH INCREASING TRANSFORMATION TIME

Specimen	Austenitizing Temp., ° C.	Finish Forging Temp., ° C.	Hardness, D.P.N.	Microstructure
i	1150	980*	220–230	Completely transformed
j	1150	>980†	225–240	Completely transformed except for larger grains

* Outer edge † Interior

is shown in Fig. N. Some American diagrams, though conventional, also show the range over which the precipitation of pro-eutectoid constituents occurs and the separate commencements of the overlapping pearlitic and bainitic reactions. The diagrams are also enhanced by the inclusion on the right-hand side of the hardness of the end products.

With reference to the practical value of the Atlas, there has, I think, been some over-emphasis of the limitations of the use of diagrams and the factors which must be taken into consideration. In our experience we have found that the diagrams can be used with considerable confidence. To take an example, despite differences in analysis, method of manufacture, size of bars, etc., it has been found that by referring to the appropriate **S** curves a compromise isothermal annealing treatment can be successfully carried out on four or five steels all in one batch. A significant contribution to productivity has resulted.

In choosing steels for various applications there is one important aspect which is well illustrated in these curves. With a steel like, say, En 25 the transformation through the pearlite range takes some 17 hr. and is a difficult and long procedure. However, reference to the **S** curves shows that a steel with similar hardenability and general properties, like En 40 (En 29 is also similar) requires only 1 hr. to transform, at its appropriate temperature, completely to pearlite, and this temperature is also in a less critical range.

There are various types of constructional steels the **S** curves of which are not included in this compendium. Some laboratories have, I know, obtained curves for the case and core of the carburizing steels, and perhaps these and others of value could be collected together in a second volume.

The factors at play in the decomposition of austenite are illustrated in a fascinating manner on turning over the pages of this Atlas, and the diagrams could with advantage be further studied from the more academic view. For instance, the study of the effect of the various alloying elements on the pearlitic, bainitic, and martensitic regions, the morphology of the products of decomposition, the phenomena of diffusion, nucleation, and growth, and so on may be considered.

Mr. **C. E. Mavrocordatos** (English Steel Corporation, Ltd.) : A problem not entirely unrelated to the correlation of transformations during continuous cooling and during isothermal conditions, concerns steels which precipitate a primary phase. It is not quite clear yet what is the effect of pre-precipitation of ferrite on the subsequent transformation during a prolonged holding at a suitable temperature. Is the transformation slowed down ? Liedholm has reported* that pre-precipitation of ferrite—such as may occur during the cooling of a large forging from the austenitizing temperature to the temperature at which it is to be held for isothermal annealing—will slow down the rate of transformation. This is a problem of very great industrial interest.

The problem of any further work can be approached in two ways, namely (*a*) to determine the **S** curves of all the remaining En steels, or (*b*) to concentrate on a few basic compositions and build them up by judicious additions of alloying elements so as to evaluate the effect of these elements on the basic composition, singly or in combinations.

The curves presented in the Atlas refer to the transformation characteristics of the steels after heating to ordinary normalizing temperatures. The effect of higher initial temperature can be most profound on the transformation characteristics, as is very well known.

* *Metal Progress*, 1948, vol. 54, pp. 849–856.

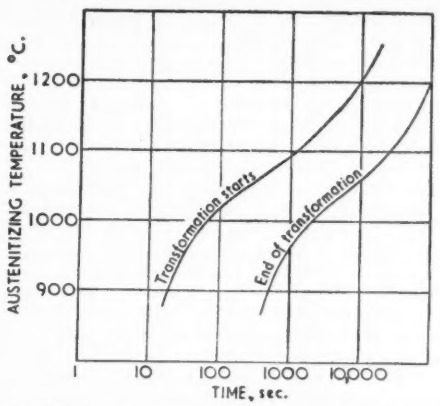


Fig. O—Effect of austenitizing temperature on the transformation characteristics at 710° C. of a die-liner steel

All the steels do not react in the same way, however, and comparisons, even between similar types of steels, may be misleading. The method we have adopted in the laboratory of the English Steel Corporation is to fix the transformation temperature of a steel—usually the temperature of the fastest transformation in the pearlite range—and to carry out a few tests at this temperature with test pieces which have been austenitized at progressively higher temperatures up to forging temperatures. The times of the beginning and end of the transformation at this constant temperature can then be plotted against the austenitizing temperatures, as shown in Fig. O. Such a test, apart from yielding direct information on the behaviour of the steel after forging, also offers some qualitative indication on the effect of grain growth, complete solution of excess phases, etc., on transformation. Isothermal transformation diagrams can be more valuable to the heat-treater when supplemented with such data.

Finally, with reference to the difficulty of determining the **S** curves of fast transforming steels, I have gained the impression that the delicate Stanton dilatometer, using specimens of very thin wire, can be too sensitive. The original work of Davenport and Bain was carried out with thin foil in a dilatometer similar to the one used today, but the test piece was held in tension rather than in compression. The solution of the problem of fast-transforming steels may eventually be found in this method where very thin sections can be used. The microscopic work is far too tedious and elaborate, and X-rays do not seem, at the moment, to offer any help, as they rely on air-cooling rather than on quenching from the austenitizing temperature to the test temperature.

Mr. **P. T. Moore** (Imperial College of Science and Technology) : Since the martensitic transformation is certainly not an equilibrium reaction, why is an M_s line shown on the iron–carbon diagram (Fig. 1 of the Atlas) ? Also, how were the M_s temperatures of the steels determined ? I ask this because I observe that steel En 12 (page 17) has a reported M_s of 360° C., but an isothermal test was carried out at 350° C., the results of which are not shown. Similarly, on En 23 steel (page 35) the M_s is shown as 305° C., whilst a test carried out at 300° C. gave a product with a hardness of only 460 D.P.N. when fully transformed. Surely this is not 100% martensite.

While I would not suggest that all different types of transformation should be indicated on the diagrams, the usefulness of the curves would be greatly increased if pro-eutectoid constituents, particularly ferrite, were

shown separately. As an example, I would quote steel En 24. I have carefully determined the isothermal curve, using samples prepared from the same cast as those used for determinations in the Atlas, and I find that in the temperature range 650–700° C. the start line of the pearlite transformation corresponds closely to the 0% transformation line in the Atlas, while the pro-eutectoid ferrite reaction begins considerably earlier.

I would question the general use of isothermal diagrams, even indirectly, for determining the hardenability of a steel. Surely it is easier to carry out Jominy tests, thus obtaining a practical measure of hardenability, rather than to determine the **S** curve for the steel.

It is stated that for En 25 and En 27 steels satisfactory agreement was secured between transformation diagrams obtained from both wire and mid-radius specimens. I am surprised that the curves are so similar in view of the completely different microstructures of these specimens, as shown in Figs. 6 and 7. The Report states that the wire specimen has, as would be expected, a finer and more uniform structure than the specimen machined from 1⅛-in. bar. Since all grain-size determinations were made on 1⅛-in. bar, these surely cannot be read in conjunction with an **S** curve determined on 11 S.W.G. wire, for it is well known that changes in grain size affect the transformation characteristics considerably.

I believe that 50° C. intervals—which were taken as standard for the determination of the diagrams—are, in general, too large. In support of this contention I would refer to the lower diagram of Fig. 8, and particularly to the test carried out at about 570° C. What justification is there for drawing a kink in the curve of 50% transformation, on the evidence of only one point ?

In regard to experimental limitations in the determination of **S** curves of fast-transforming steels, the inherent difficulty is the rapid quenching of the specimen to transformation temperature. I spent six months building an apparatus which I believed would enable faster transformation to be plotted, and I am sorry to say that it was not in any way a success. I have had to resort to a slower transforming steel for my purpose, and I can visualize no great improvement over the present methods of quenching.

Mr. **A. R. G. Brown** (British Iron and Steel Research Association) : In the practical application of **S** curves the variation in position of the curves both within a cast and within a given British Standard Specification is of great importance. These variations are well known, and I would suggest that within a given specification it is possible to obtain a time factor of up to ten times. Such a factor for the start of transformation lines assumes considerable importance in the development of heat-treatment schedules, affecting in particular the largest size of specimen that could be given a specific treatment with success. No details of the effects of previous treatment are given, but only the results obtained. I realize the magnitude of the task involved in obtaining such information, but it is generally agreed that the previous treatment of the material is of importance, particularly, as has been stressed already by other speakers, the prior mechanical working and the time and temperature of austenitizing.

The agreement between various co-operating laboratories is also of interest. Figure 9 in the Atlas shows the results from three laboratories. I appreciate that the determination of the beginning and end of transformation is difficult, but for the given steel the start of transformation at 350° C. is given as 85, 41, and 60 sec. I do not suggest that this is not a reasonable agreement, especially in view of the close agreement in the 10, 50, and 90% transformation lines, but a difference of 40 sec. for the incubation period merits attention. Referring again to Fig. 9, I notice that in two cases a number of complete curves in the pearlite range are sketched in on the basis of one point. I cannot believe that that is the sole evidence for these curves.

The normal range of engineering steels in use has been well covered, though curves for fast-transforming and slow-transforming steels would be of interest. The difficulties involved in the determination of curves for fast-transforming steels are great. I have carried out some work with fast-transforming plain carbon steels and found it impossible to quench small tensile test pieces (cross-sectional area $\frac{1}{100}$ sq. in.) without transformation in the pearlitic range.

Dr. **T. Ko** (University of Birmingham) : It is stated on page 14 of the Atlas that if slower cooling rather than a rapid quench is used, the time of cooling to the temperature of isothermal transformation must be taken into consideration. In his introduction Dr. Pfeil also emphasized the importance of such factors. I wish now to draw attention to the effect of slow cooling on isothermal transformation diagrams.

Jenkins, Bucknall, and Jenkins* reported the results of the thermal analysis of a nickel–chromium–molybdenum steel (steel No. 12 ; C 0·34%, Cr 0·78%, Ni 3·53%, Mo 0·39%) which has a composition lying between those of steels En 23 and En 28 in the Atlas. These authors very slowly cooled specimens at 50° C. per day to 625°, 525°, and 425° C. and held them at these temperatures for one day ; Fig. P compares their results with the isothermal transformation diagrams of En 23 and En 28. Even if we neglect the time required to cool the specimens to the temperatures mentioned (4, 6, and 8 days, respectively), we would expect the specimens after one day at temperature, if there were no change due to slow cooling, to contain 50–100% pearlite at 625° C. and 50–90% bainite at 425°. In fact, the amount of transformation estimated from the photomicrographs given in the Report is about 5% at 625° C. and 30–40% at 425° C. If we take into consideration the time required for cooling to the temperature of isothermal transformation we expect the steel to be fully pearlitic in all cases. Judging from the coarseness of the martensite, there is no appreciable difference in the austenitic grain size owing to slow cooling. The slow cooling used in this experiment is rarely encountered in actual practice, but there might be similar effects at a higher cooling rate in steels with a faster pearlitic transformation. Liedholm† has observed that the formation of ferrite during slow cooling to isothermal transformation temperatures also greatly retards the subsequent transformation to bainite in a hypo-eutectoid steel.

Mr. S. A. Cottrell, of Birmingham University, has examined the bainitic transformation of another two steels (steel VA and steel VB) of the En 25 type. These steels are of very similar composition, and one (VA) is made by the acid open-hearth process and the other by the basic electric-arc furnace ; chemical analyses of the steels are as follows :

	Steel VA	Steel VB
Carbon, %	0·33	0·32
Silicon, %	0·20	0·22
Manganese, %	0·68	0·63
Nickel, %	2·59	2·60
Chromium, %	0·53	0·51
Molybdenum, %	0·58	0·55
Phosphorus, %	0·029	0·023
Sulphur, %	0·039	0·028

* *The Iron and Steel Institute*, 1939, *Special Report No.* 24, p. 181.

† *Transactions of the American Society for Metals*, 1947, vol. 38, p. 180.

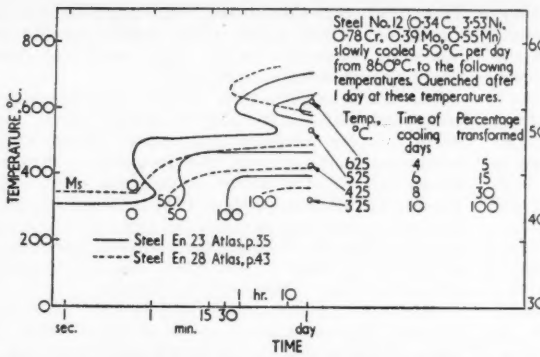

Steel No.12 (0·34 C, 3·53 Ni, 0·78 Cr, 0·39 Mo, 0·55 Mn) slowly cooled 50°C. per day from 860°C. to the following temperatures. Quenched after 1 day at these temperatures.
Temp., °C.
Time of cooling days
Percentage transformed
625 4 5
525 6 15
425 8 30
325 10 100
Ms
Steel En 23 Atlas, p.35
Steel En 28 Atlas, p.43
TEMPERATURE, °C.
TIME
sec.
min.
hr.
day

Fig. P—Comparison of Jenkins and co-workers' results with isothermal transformation diagrams of En 23 and En 28

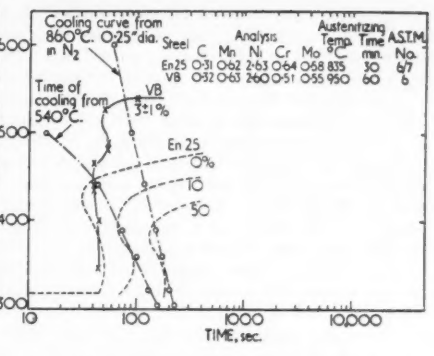


Fig. Q—Incubation periods of VB steel, with data for En 25

In Fig. Q the incubation periods of VB steel (the continuous line) are shown, together with the 0, 10, and 50% lines given in the Atlas for En 25. The incubation periods for the two steels VA and VB are very similar in length except in the temperature range above the kink, where VA steel begins to transform slightly earlier at 40 sec. It will be noticed that the top of the bainitic shelf, at 540° C., is much higher than that for the En 25 steel, which is at 480° C. The austenitizing temperature and time used are different, being 950° C. and 1 hr. for the VA and VB steels and 835° C. and 30 min. for En 25, but we have sufficient evidence, including several specimens austenitized at 835° C., to exclude this difference as the possible cause of the difference in the position of the shelf. Both VA and VB steels in the form of ½-in. diameter bars, when cooled in still nitrogen from 950° C., gave a fully martensitic structure.

The most recent method of calculating hardenability from the isothermal transformation diagram, which has the merit of simplicity, is that due to Jones and Pumphrey.* They assumed, among other things, that during continuous cooling the fractional nucleation times (that is, the time spent at one temperature divided by the induction period at that temperature) are additive in one transformation range and independent of the other range. Transformation will begin when the sum of such fractional nucleation times in one range is equal to unity. The diagram shown for VB steel provides a very good opportunity to check the validity of this assumption in this type of steel. The cooling curve on the left of Fig. Q shows the time required to cool the ½-in. diameter specimens to a particular temperature from 540° C. Because the incubation period is almost independent of the temperature of isothermal transformation below 540° C., we would expect transformation to begin when this cooling curve intercepts the isothermal transformation diagram if the assumption is valid, and the specimen after cooling should contain at least 20–30% of bainite formed between 440° and 320° C. The specimens, as already mentioned, contained no bainite and the structure was fully martensitic.

The Atlas has mentioned the effect of austenitizing temperature on the transformation diagram; Cottrell has examined the incubation periods of the bainitic transformation of the same En 31 steel austenitized at 950° C. for 1 hr. (A.S.T.M. grain size No. 6). The time required to give 3 ± 1% of transformation is twice the incubation period given in the Atlas at 320° C., six times at 400° C., eight times at 450° C., and sixteen times at 500° C. This no doubt is due to the more complete solution of the carbide. At the original austenitizing temperature employed, an appreciable amount of residual carbide was left undissolved.

Although the austenitizing conditions used in determining the diagrams given in the Atlas were adjusted to meet practical requirements, the conditions for some of the steels, such as En 18, 21, 28, 40, and 56, had probably produced a reasonably homogeneous austenite, and it would be very useful to those interested in the kinetics of austenite transformation if details of the transformation, such as the nature of the pro-pearlitic transformation products and the end of such transformation, if available, could be given in a supplementary publication.

Mr. **F. D. Waterfall** (Imperial Chemical Industries, Ltd.): My contribution to this discussion will be from the practical angle, that of a user of the Atlas. This Atlas provides at least something to work on during isothermal treatment (or even simple quenching) of parts, and perhaps it is of more value in this respect than the authors claim.

A list is given on pages 14–15 of the Atlas of steels "which might be suitable for martempering in appropriate sections." Presumably many of the steels in the Atlas have been considered unsatisfactory for martempering because partial transformation takes place during the time in the quenching bath held at a temperature just above the M_s point. It does not necessarily follow that steels in which partial transformation occurs in this way are unsuitable for martempering. Such steels in the quenched condition after martempering would consist of a mixture of bainite and martensite (mostly martensite) and frequently have a hardness sufficiently high for the purpose in mind. We have found from tests that the speed of cooling in a rapidly circulated nitrate–nitrite salt used for quenching is approximately that obtained during quenching in warm oil. For this reason we normally state that a steel which can be hardened with an oil quench can also be martempered satisfactorily, a measure of bainite along with martensite in the *hardened* condition having a beneficial rather than adverse effect on the toughness, whilst affecting the hardness little (we fully accept the statement that the higher alloyed steels used in the intermediate tensile ranges give a better combination of physical properties when hardened and tempered, than by *austempering* to give the same hardness).

The usefulness of the diagrams would be much increased if we were able to relate them with continuous-cooling curves. As it is, a practical man with the Atlas before

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, pp. 137–144.

him and a given size of steel to treat either by martempering or oil quenching has no means of knowing whether, or where, the part during quenching cuts the **S** curve. One publication of **S** curves for nickel steels, by the International Nickel Company,* carries also a transparency of continuous-cooling curves (ranging from 1000° F. to 25° F. per second and 1000° F. to 25° F. per minute) which can be superimposed on the **S** curves to give an idea how a piece cooling at a given rate cools in relation to the **S** curve. Coupled with the use of this transparency is the need for a knowledge of how fast a given bar size cools when quenched in the chosen quenching medium. Here again this information is available (for water-, oil- or air-cooling) in the publication to which reference has been made. Could not rates-of-cooling curves be supplied likewise for use with the Atlas ?

Case-hardening steels are now being martempered in appreciable quantities, both on the Continent and in America. It would be useful to have transformation diagrams for the En case-hardening steels as applying to both the uncarburized steel and to its carburized case, the latter containing say 0·90–1·0% of carbon. Similar curves for the more common of the existing alloy tool steels would be valuable, since many of these are now being martempered.

CORRESPONDENCE

Mr. **I. Walker** (Humber, Ltd.) wrote : As a user of steels I have found the Atlas of isothermal diagrams extremely helpful, but I would like to suggest one or two modifications that would considerably increase their usefulness.

In using the diagrams to determine isothermal annealing times and temperatures it has been our experience that some casts of steel give results widely different from those indicated in the Atlas, even though the analyses are still within the limits of the specification. It is suggested therefore that the usefulness of the diagrams could be greatly increased if maximum and minimum limits of transformation were indicated for the variations of chemical analyses. These could be presented in a form similar to the hardenability bands already presented in other papers. It is appreciated that in order to determine the limits for these bands a considerable amount of work would need to be undertaken, but such an indication is necessary if the diagrams are to be of use to industry. The limits for any particular analysis are especially important for the deeper-hardening steels, where a small inaccuracy on the right of the diagram may mean several hours difference in soaking time for transformation.

It would also appear to be particularly unfortunate that some of the steels selected had analyses and hardenabilities that were not representative of the specification. For example, on page 28 of the Atlas the En 18 steel selected has a carbon content of 0·48%, whereas the steel widely used in the motor-car industry is to specification En 18C with a limiting carbon range of 0·35–0·38%. The only information that is given regarding a steel of this type is in the comments that one of the collaborating laboratories examined a steel with a 0·39% carbon content and found that it gave rather a different curve.

AUTHORS' REPLY

Dr. **L. B. Pfeil,** on behalf of the Sub-Committee, wrote in reply : I would like to express, on behalf of the Isothermal Transformation Group and of the Thermal Treatment Sub-Committee, our appreciation of this discussion. Only a few items require specific answers but some comments on the more important themes of the discussion are appropriate.

The remarks of several of the speakers have been concerned with the decision to determine the diagrams using samples machined from wire. Longitudinal and transverse variations of transformation characteristics are known to exist within commercial steel, but, since almost the full cross-section of the material is represented in dilatometer samples machined from wire, it is believed that the diagrams obtained are more representative of the average behaviour of the steels than could have been obtained by any other simple procedure.

Adequate information is still lacking on the extent to which the transformation characteristics of individual zones of billets and bars deviate from the average. This information would be required before the Group would be able to provide the diagrams, representative of the extremes in transformation characteristics of each B.S. En type, which several contributers to the discussion have requested. Even if this information were available, a study of steels of compositions corresponding to the upper and lower limits of the permitted composition ranges would be inappropriate, since these ranges are, in effect, often further restricted by mechanical-property requirements, and the full composition ranges are seldom utilized. The task of reliably indicating the extreme transformation characteristics of each B.S. En type of steel is, therefore, formidable, and it is doubtful whether the work could be justified until reliable methods are available for the quantitative application of diagrams to normal heat-treatment procedures, the vast majority of which are anisothermal.

The problem of relating isothermal diagrams to continuous cooling conditions is one that has often been referred to in the discussion. Although the Group is convinced that much valuable qualitative and semi-quantitative information can be obtained from isothermal data, it is not prepared to recommend a method of forecasting the manner in which a steel will transform when cooled at a finite rate through the transformation range. Some of the contributions to the discussion support this cautious attitude, although it is interesting to note the success claimed by Mr. Cottrell.

The importance of providing information on transformations occurring under anisothermal conditions is fully appreciated, and will be borne in mind in planning future work. The many other lines of study proposed will also receive the careful consideration of the Group; in fact, a number are already under active investigation.

Mr. Hodgson is correct in his implication that the low pearlite reaction rates of the En 21 steel studied were due to residual molybdenum. The steel contained 0·14% of this element.

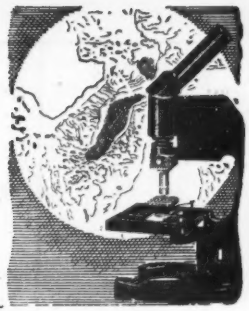
Mr. Moore's comments regarding the tests made at temperatures below the M_s temperature are difficult to appreciate. It is now generally accepted that at temperatures between the M_s and M_f the formation of martensite may be followed by isothermal transformation. The kink in the 50% transformation curve of Fig. 8, to which he refers, represents the intersection of the pearlite and bainite transformation ranges. The dilatation curves and microstructural evidence left no doubt about the existence of the discontinuity.

Mr. Brown criticizes certain features of Fig. 9. It should be explained that a complete set of experimental data was not available for the pearlite range of the third diagram of this illustration. Curves were nevertheless drawn to facilitate comparisons of the three sets of experimental points provided by the collaborating laboratories.

* " Isothermal Transformation Diagrams for Nickel Alloy Steels." New York, 1947 : International Nickel Co.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Studies in the Deoxidation of Iron

DEOXIDATION BY MANGANESE

By H. A. Sloman, M.A., F.R.I.C., F.I.M., and E. Ll. Evans, B.Sc.

SYNOPSIS

The preparation, analysis, and microscopical examination of a series of ingots, made by adding oxygen and manganese to 300–400 g. melts of pure iron, are described. The analyses reported include estimations of the total oxygen and manganese contents of the ingots, and chemical and X-ray analyses of the non-metallic inclusions obtained by alcoholic-iodine extraction. The product of deoxidation of iron by manganese is found to be the double oxide (Mn,Fe)O, the composition of which varies continuously with the metallic-manganese content of the alloy with which it is associated. The microscopical appearance of the inclusions in polished metal sections is described. The alcoholic-iodine method is shown to be unsatisfactory for the quantitative extraction of inclusions with a high MnO content.

In the Appendix, a new calculation of the equilibrium conditions for deoxidation by manganese, using previously published data, is given. The experimentally determined composition of the double-oxide phase in an alloy of given manganese content is shown to be in reasonable agreement with that derived by calculation of the equilibrium at 1527° C. (1800° K.) between the alloy and a solid slag.

THE experimental work reported in this paper forms part of an investigation of the nature and mechanism of formation of products of deoxidation by various elements, with special reference to their analysis, identification, and microscopical examination, and to the correlation of observed phenomena with certain physico-chemical considerations.

The methods used in this work to prepare, analyse, and examine samples of iron deoxidized by manganese were substantially the same as those described in an earlier report[1] on deoxidation by aluminium.

PREPARATION AND SAMPLING OF INGOTS

The first nine ingots (*A–J*) in the series were prepared by melting charges of 300–400 g. of N.P.L. Mark 2 iron[2] in an alumina crucible in a high-frequency induction furnace. An initial addition of 0·02% of oxygen was made to each charge by placing an appropriate amount of ferric oxide in a plugged hole at the base of the charge. Manganese in the form either of high-purity 50% ferro-manganese (for ingots *A*, *B*, *C*, and *F*) or of cleaned electrolytic manganese (for ingots *D*, *E*, *G*, *H*, and *J*) was added by pushing it into the iron, shortly after the latter had melted, by means of a magnetic ram. In all the melting experiments, the temperature was kept within 50° C. of the melting point of iron. After allowing sufficient time (about 20 sec.) for the metals to become thoroughly mixed, the power was cut off and the contents of the crucible were allowed to solidify *in situ*.

Parts of the melting procedure were modified during the investigation. The first preparations were carried out *in vacuo*, and it was found that a serious loss of manganese occurred by volatilization. This loss was noticed even from the more dilute solutions, and occurred irrespective of whether ferro-manganese or pure manganese was used. Accordingly, later melts were carried out under argon at atmospheric pressure. As consideration of the analytical results will show, this precaution did not entirely prevent loss of manganese.

The slip-cast alumina crucibles first used (for melts *A*, *B*, and *D*) were from a batch that had been fired at 1500–1550° C. Although somewhat porous, these crucibles had been found quite satisfactory for preparing ferrous alloys from oxygen-free materials, or for melting oxidized pure iron. The oxides formed in the present experiments, however, appeared to react appreciably with the alumina, and the ensuing contamination of the melt gave rise to a high proportion of complex oxides in the non-metallic inclusions. Crucibles for subsequent use were, therefore, fired at 1750° C., and the improved resistance of the alumina to scouring and to chemical reaction led to a lower alumina content in the inclusions.

Paper SM/BB/161/50 of the Gases and Non-Metallics Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 3rd March, 1951. The views expressed are the authors', and are not necessarily endorsed by the Sub-Committee as a body.

Mr. Sloman and Mr. Evans are at the National Physical Laboratory, Teddington.

XUM

Table I—RESULTS OF CHEMICAL ANALYSES OF INGOTS DEOXIDIZED BY MANGANESE

Ingot	Mn Introduced, wt.-%	O_2 Introduced, wt.-%	Chemical Analysis of Alcoholic-Iodine Residues, wt.-% of Ingot sample									Total Oxygen, wt.-%		Metallic Manganese in Solution, wt.-% (4)-(14)	MnO in $(Mn,Fe)O$ Solid Solution, %	
			SiO_2		Al_2O_3		P_2O_5	FeO		MnO					Alcoholic-Iodine Residue	X-Ray Analysis
			Oxide	Oxygen	Oxide	Oxygen		Oxide	Oxygen	Oxide	Oxygen	Metal	Alcoholic-Iodine Residue	Vacuum Fusion		
	Total Mn, wt.-%															
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
A	Nil	0·02	0·004	0·006	0·003	0·016	0·008	0·001	0·101	0·025	0·003	0·001	0·002	0·037	0·039	0·002	4	10
B	0·1	0·02	0·07	0·002	0·001	0·010	0·005	0·001	0·021	0·005	0·012	0·003	0·009	0·014	0·013	0·06	38	50
C	0·3	0·02	0·26	0·002	0·001	0·005	0·002	0·001	0·019	0·004	0·029	0·006,	0·022	0·013,	0·014	0·24	60	70–80
D	1·2	0·02	0·74	0·0007	0·0004	0·003,	0·003,	•	0·007,	0·001,	0·019	0·004,	0·015	0·010	0·033	0·52,	72	95
E	0·8	0·02	0·53	0·004	0·002	0·003	0·001,	0·001	0·006	0·001,	0·027	0·006	0·021	0·010	0·012	0·71	82	90
F	2·5	0·02	0·80	0·004	0·002	0·007	0·003	•	0·004,	0·001	0·016,	0·003,	0·013	0·010	Top 0·015, Bottom 0·014	0·79	80	90
G	2·5	0·02	1·76	0·002	0·001	•	•	•	0·007	0·001,	0·013	0·002,	0·010	0·005,	0·025	1·75	65	95
H	3·0	0·02	1·81	0·002	0·001	trace	•	•	0·004	0·001	0·046	0·010	0·036	0·012	0·033	1·77	92	95
J	5·0	0·02	3·80	0·003	0·001,	trace	•	•	0·002,	0·0006	0·017	0·004	0·013	0·006	0·015	3·79	85	95
K	1·05	0·57	0·13	•	•	•	•	•	0·390	0·087	0·128	0·029	0·099	•	•	0·03	25	30

• Not determined

Complete longitudinal half-sections of several ingots were polished and examined for segregation of the inclusions. No concentration toward the outer surface of the ingot was observed. Vacuum-fusion analyses for total oxygen of specimens from the top and bottom halves of several ingots showed only a slight tendency for the inclusions to be segregated toward the top; the figures given in Table I for ingot *F* are typical. Although this does not imply that segregation is unlikely under any solidification conditions, or at any concentration of manganese or oxygen, it indicated that in the present work the only precaution needed before sampling was to file the ingot surface to remove tarnish or adhering crucible material. (In the study of deoxidation by aluminium[1] it had been found necessary to remove at least the outer 2-mm. layer, owing to the segregation to this region of large agglomerates of inclusions.)

The filed ingots were cut longitudinally into quarters; apart from those analysed at top and bottom, samples were taken from around the centre, in the following forms:

(*a*) Cylindrical pieces for vacuum-fusion analysis
(*b*) Plates, 1–1·5 mm. thick, for alcoholic-iodine extraction (one sample for chemical analysis, one for X-ray examination, of the residue).
(*c*) Millings for chemical analysis of manganese.

The tenth ingot (*K*) of the series was prepared for the study of the effects on equilibrium in the metal of the presence of a large quantity of slag. A large hole was drilled in a length of bar of an iron alloy containing 1·05% of manganese. Into this hole was sealed a mixture of some of the drillings with a quantity of ferric oxide equivalent to an addition of 0·57% of oxygen (≡ 2·0 at.-%). The drillings were included to facilitate reaction between oxide and iron before the charge melted. This prevented the excessive 'boiling' of the melt which had been experienced in an earlier experiment in which a large amount of oxide was added to a massive charge.

ANALYSIS OF THE INGOTS

The alcoholic-iodine extractions of the non-metallic inclusions from the ingots *A*, *B*, *C*, *E*, and *G* were carried out in the normal way[3] with the solution at a temperature of 65° C. In view of earlier observations by Rooney[4] during the analysis of samples of low-carbon basic Bessemer steel, it was expected that inclusions rich in manganous oxide would be partly or wholly soluble in the hot solution. In the present investigation this effect first became apparent with ingot *D*, and, in an attempt to reduce the loss, the remaining extractions (of ingots *D*, *F*, *G*, *H*, *J*, and *K*) were carried out at temperatures not exceeding 30° C. This, however, did not completely overcome the loss of manganous oxide from manganese-rich inclusions. The filtered residues were ignited, and the various oxides were determined gravimetrically.

All the residues for X-ray examination and for identification by the Debye-Scherrer method were extracted at 30° C.; they were washed from the filter paper with benzene, applied with a camel-hair brush. Some amounts were so small that difficulty was experienced in obtaining satisfactory X-ray photographs. The total oxygen contents of the ingots were determined by the vacuum-fusion method, and the total manganese contents by chemical analysis.

ANALYTICAL RESULTS

The results of the analyses and of the X-ray examination of the residues are summarized in Tables I and II respectively. The ingots, with the exception of *K*, are arranged in order of increasing manganese content. Four ingots have oxygen

contents which, as determined by the vacuum-fusion method, are in excess of the amount of oxygen (0·02%) added. This arose either from the use of incompletely deoxidized iron as the charge, or from the accidental ingress of oxygen to the system during melting.

The major constituent of the inclusions is a solid solution of manganous and ferrous oxides (Mn,Fe)O, the composition of which changes with the manganese content of the metal. This is given in column 17 of Table I as the difference between the total manganese determined chemically (column 4) and the amount of manganese associated with the inclusions (column 14). Two estimates are given in Table I of the concentration of manganous oxide in the solid solution oxide phase: in column 18 as a percentage of the total manganous (column 12) and ferrous (column 10) oxides, determined gravimetrically, and in column 19 as an estimate derived from the X-ray measurements by Jay and Andrews[5] of the parameters of the FeO–MnO system. The concentration of MnO in the (Mn,Fe)O inclusions, as derived from X-ray measurements, is always higher than that given by chemical analysis (*see* p. 149). The continuity of the variation in composition of the oxide phase with increasing manganese, from 100% of FeO to 100% of MnO, is consistent with the formation by the two oxides of a continuous solid solution, and the results therefore confirm the work of Jay and Andrews.[5] No evidence was found to support the existence of a second phase as shown by Hay, Howat, and White[6] in their equilibrium diagram of the FeO–MnO system.

The concentration of MnO in the (Mn,Fe)O inclusions, as determined by X-ray analysis, reaches 90% when the metallic manganese content of the metal is between 0·5 and 0·7%. Inclusions associated with manganese contents above this amount contain manganous oxide in proportions varying between 90 and 100%. Lack of a clear continuous variation in this range may be attributed to the very small free-energy differences between oxides of these compositions (*see* p. 150). Slight variations in the amounts of trace impurities, such as sulphur or phosphorus, could exert a large effect relative to that of additional manganese.

A significant feature of the results is the discrepancy, in several cases, between the values for total oxygen as determined by vacuum-fusion and alcoholic-iodine methods. The vacuum-fusion figure for oxygen is appreciably higher than that given by the alcoholic-iodine method for those ingots in which the inclusions contain 90% or more of MnO. The discrepancy was not overcome when a lower extraction temperature of 30° C. was used (*see* Table I). This confirms the view of Rooney,[4] and it must be concluded that the alcoholic-iodine method, even when operated at a temperature as low as 30° C., is unreliable for the quantitative extraction of inclusions of this type.

X-ray analysis of the residues (*see* Table II) shows that most of them contain one or more substances, in addition to (Mn,Fe)O, arising from the presence of trace impurities such as silicon and sulphur in the iron, and from attack of the alumina crucible. An effect incidental to the solution of manganous oxide during alcoholic-iodine extraction is that these extraneous substances are left in the residue in higher proportions, relative to (Mn,Fe)O, than those in which they occur in the metal. Thus the amount of manganous oxide in the residue from ingot *J* is, according to X-ray analysis, of the same order as the amounts of tephroite and manganous sulphide, whereas microscopical examination of the ingot shows that the (Mn,Fe)O inclusions predominate.

A large amount of slag was formed in the preparation of ingot *K*. It reacted strongly with the alumina crucible, and its final alumina content was high. According to X-ray analysis, the slag consisted of hercynite ($FeO.Al_2O_3$) and manganous-ferrous oxide solid solution containing 30% of MnO, in the proportions of approximately 2 : 1. X-ray examination of an alcoholic-iodine residue from the ingot showed it to consist of (Mn,Fe)O having a parameter corresponding to a concentration of 30% of MnO. No other compound was detected. Chemical analysis of a second residue gave the proportion of MnO as 25%. Although no direct determination of alumina in the residue was made, it was shown by difference not to exceed 5%, and was probably much less.

Microscopical Examination

Polished unetched sections of the ingots were examined on a Beck No. 50 Universal microscope, mainly with a 3·75-mm. semi-apochromatic oil-immersion objective, at a magnification of 1000 dia. For visual examination, illumination was provided by a tungsten-filament lamp corrected by a Chance OB9 filter to simulate normal daylight. Photomicrographs were taken with illumination from a filtered mercury-vapour lamp.

Only those inclusions that appeared typical throughout the series were examined. In every sample

Table II—RESULTS OF X-RAY ANALYSES OF ALCOHOLIC-IODINE RESIDUES FROM INGOTS DEOXIDIZED BY MANGANESE

Compounds Identified and their Estimated Proportions

Ingot	(Mn,Fe)O	Estimated MnO, %	Spinel $MnO.Al_2O_3$	Tephroite $2MnO.SiO_2$	Manganous Sulphide MnS	Rhodonite $MnO.SiO_2$	Almandine $3FeO.Al_2O_3.3SiO_2$	α-tridymite SiO_2	Other Constituents and Unidentified Lines	Ignited Residue, wt.-% of Steel
A	Large	<10	Medium	..	..	..	..	..	Some Fe_2O_4	0·13
B	Large	45–50	Large	Trace	..	..	Trace	..	..	0·050
C	Large	70–80	Trace	Trace	..	..	Trace	..	..	0·061
D	Medium	>95	Small	..	Medium	..	..	Medium	..	0·037
E	Medium	90	Trace	Small	..	..	Trace	..	..	0·046
F	Large	90	..	Small	Large	..	..	..	Very weak lines	0·032
G	Medium	>95	..	..	..	Medium	..	Small	2 medium lines	0·016
H	Large	>95	..	Trace	Trace	..	..	..	Very weak lines	0 057
J	Medium	>95	..	Medium	Large	..	..	..	..	0·025
K	Large	30	..	..	..	..	..	..	..	0·58

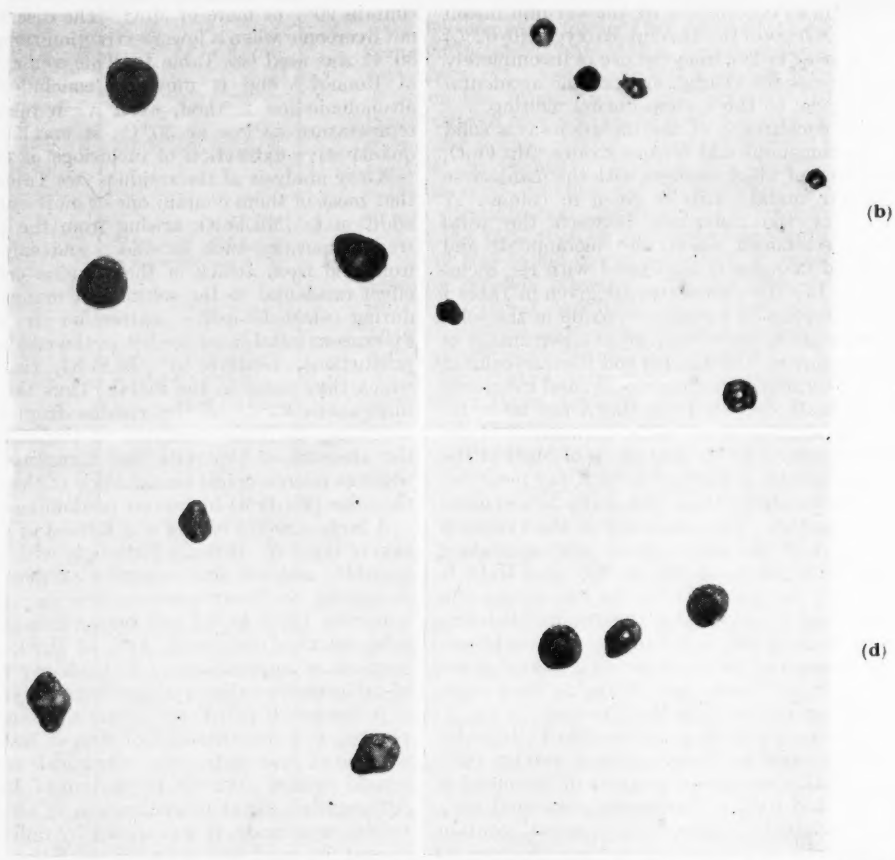


Fig. 1—Microphotographs of inclusions × 1000: (*a*) 25–30% MnO; (*b*) 60–80% MnO; (*c*) >95% MnO; (*d*) 60–80% MnO, showing duplex inclusions

these consisted of the double oxide (Mn,Fe)O, the appearance of which was consistent with descriptions given by Portevin and Castro,[7] and by Hay *et al.*[6] Those containing a high proportion of ferrous oxide were spherical, and grey in colour, resembling ferrous oxide. The red transmission colour reported by Portevin and Castro[7] was not discerned. A small proportion of the inclusions, estimated to contain about 30% of manganous oxide (Fig. 1*a*), was faintly transparent, but the transmission colour appeared green. As the proportion of manganous oxide increased (above 50%) the inclusions retained their grey appearance by reflection, but became increasingly transparent with green transmission (Fig. 1*b*). The outline became more irregular, and at compositions approaching 100% of manganous oxide there was a marked tendency to form dendrites, which in section had the form of rounded three- or four-pointed stars (Fig. 1*c*). No inclusions were seen having the highly developed dendritic form reported by Körber and Oelsen,[8] but this may have been due to differences in experimental conditions such as rates of cooling. There was no evidence of a eutectic structure, as implied by Hay *et al.*,[6] at any composition.

In most of the ingots, a fairly large number of the inclusions were duplex in appearance. The constituent, other than the double oxide which has been described, was present in amounts consistent with those of the extraneous compounds determined by chemical and X-ray analyses. The most characteristic of these was found particularly with the inclusions of higher MnO content; it was pale grey, in the form of an extended globule at the metal/inclusion interface (Fig. 1*d*). The X-ray analyses of the alcoholic-iodine residues clearly indicate that this phase consists of manganous sulphide and not ferrous oxide, although its mode of occurrence has probably led to the occasional reports of the coexistence of FeO and (Mn,Fe)O as a eutectic in inclusions. In support of this conclusion, the application of Whiteley's silver nitrate test[9] to the polished sections gave a positive indication on a large proportion of these grey inclusion constituents.

DISCUSSION OF RESULTS

The experimental conditions were not such as to permit the determination of a reaction constant for the deoxidation of iron by manganese at any given temperature; in addition, inaccuracies in the quantitative determination of the oxides by the alcoholic-iodine method precluded even the construction of a 'deoxidation curve' that might indicate a relation-

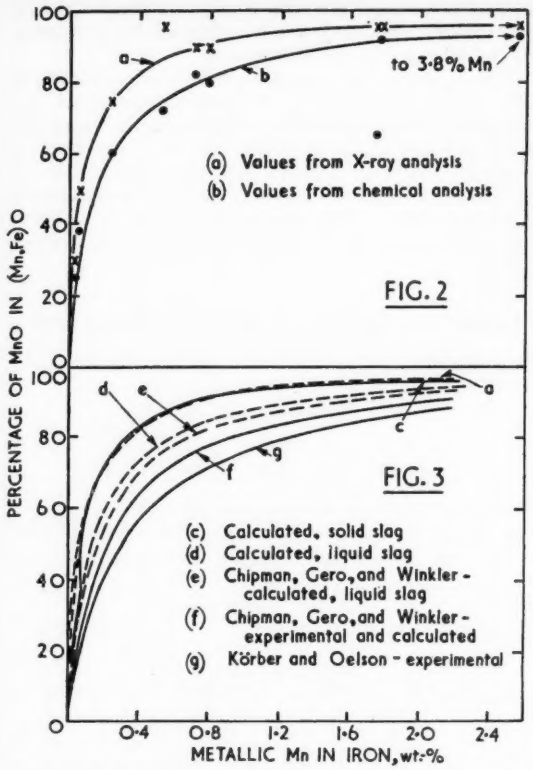

PERCENTAGE OF MnO IN (Mn,Fe)O
METALLIC Mn IN IRON, wt-%
to 3·8% Mn
(a) Values from X-ray analysis
(b) Values from chemical analysis
FIG. 2
(c) Calculated, solid slag
(d) Calculated, liquid slag
(e) Chipman, Gero, and Winkler - calculated, liquid slag
(f) Chipman, Gero, and Winkler - experimental and calculated
(g) Körber and Oelson - experimental
FIG. 3

Fig. 2—Relationship between inclusion composition and metallic manganese content of ingots

Fig. 3—Equilibrium between manganese-iron melts and (Mn,Fe)O slags at 1527° C. (1800° K.), showing curve *a* of Fig. 2 superposed.

ship between the residual manganese and oxygen in the solidified ingots. One relationship which could, however, be considered is that between the excess metallic manganese dissolved in the iron and the ratio of manganous to ferrous oxide in the inclusions. A regularity is apparent, although the results of the experimental work are not related to any specific equilibrium temperature. For purposes of comparison with theoretical calculations and with other experimental data, it may tentatively be assumed that equilibrium is 'frozen' on solidification of the alloy. The average melting point of the series is taken to be 1527° C. (1800° K.).

There is, however, a discrepancy between the MnO/FeO ratios determined by chemical analysis and those obtained by X-ray examination (*see* p. 147). This is illustrated in Fig. 2 by the deviation between curves *a* and *b*, which show that the proportion of FeO determined chemically is always greater than that determined by X-ray analysis. The deviation cannot be explained by the presence, in the alcoholic-iodine residues, of constituents other than (Mn,Fe)O (*see* Table II), which should lead to a discrepancy in the reverse direction. A possible explanation is that, when manganous oxide is dissolved by the alcoholic-iodine solution, the associated ferrous oxide remains insoluble. Although too fine (or perhaps even amorphous) to be detected by X-ray methods, the ferrous oxide could be retained at least partially by the filter paper, and would thus contribute to the figure for FeO obtained chemically. The fact that the deviation of curves *a* and *b* is greatest for those ingots containing inclusions with an MnO/FeO ratio of about 1 : 1 supports this suggestion. It is at about this composition that the proportion of ferrous oxide resulting from solution of manganous oxide would be highest relative to the initial quantity of oxide inclusions. The data derived from X-ray analyses are regarded as the more reliable in view of these possible chemical errors and also because they represent direct measurements on the (Mn,Fe)O phase.

These X-ray data may now be compared with the relationships derived from other sources. This comparison is illustrated in Fig. 3, which shows, in addition to curve *a* of Fig. 2, five other curves representing different assessments of the relationship at 1527° C. (1800° K.):

Curves *c*, *d*: From the calculation (p. 150) of the equilibrium between an iron–manganese melt and (Mn,Fe)O slags (*c*, solid slags; *d*, liquid slags)
Curve *e*: From Chipman, Gero, and Winkler's equilibrium constant, derived theoretically[10] for liquid slags
Curve *f*: From Chipman, Gero, and Winkler's equilibrium constant, derived by combining their theoretical constant with experimental results[10]
Curve *g*: From Körber and Oelsen's experimentally determined constant,[8] adjusted by Chipman.[11, 12]

From Fig. 3, it is apparent that there is coincidence between curve *a* (obtained from X-ray data) and curve *c* (determined theoretically for the equilibrium at 1527° C. (1800° K.) between the metal and the solid slag. This supports the view that the effective equilibrium temperature for the series of alloys under consideration is approximately the melting point of the alloys, and that at this temperature those slags in equilibrium with alloys containing more than a small percentage of manganese are solid. In view, however, of possible errors in the calculations, as shown by the discrepancy between curves *d* and *e* (*see* p. 150), the coincidence of curves *a* and *c* is probably fortuitous.

CONCLUSIONS

The results of the investigation are as follows:

(1) The product of deoxidation of iron by manganese is a solid solution of manganous and ferrous oxides.

(2) The evidence supports the view that these two oxides form a continuous solid solution.

(3) The manganous oxide content of the solid solution increases continuously with increasing manganese content of the metal with which the inclusions are in equilibrium. At manganese contents above about 0·7%, the inclusions consist of almost pure MnO.

(4) The composition of the inclusions determined experimentally is in good agreement with data derived theoretically for equilibrium between a solid (Mn,Fe)O slag and an iron melt containing oxygen and manganese at 1527° C. (1800° K.).

(5) It is confirmed that the manganous oxide in (Mn,Fe)O inclusions rich in MnO is soluble in alcoholic-iodine solution even at 30° C., and the alcoholic-iodine method cannot therefore be used for the

quantitative determination of this type of inclusion.

(6) The microscopical appearance of inclusions of (Mn,Fe)O varies continuously from light grey opaque ferrous oxide to the highly transparent green of almost pure manganous oxide. The form of the inclusions also changes from the spherical type characteristic of ferrous oxide to a more irregular shape, tending towards the dendritic, indicative of the higher-melting-point manganous oxide.

Acknowledgments

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APPENDIX—Determination of Equilibrium Conditions for Deoxidation by Manganese

Determination of the manganese deoxidation constant depends very largely on the experimental results of Körber and Oelsen.[8] These have led to two hypotheses which have formed the basis of subsequent theoretical derivations of the deoxidation equilibrium conditions, or have afforded a means of simplifying or curtailing experimental determinations.[10] The hypotheses are:

(1) At equilibrium at any given temperature, the quantity $\dfrac{[\mathrm{MnO}]_{\mathrm{slag}}}{[\mathrm{FeO}]_{\mathrm{slag}}[\mathrm{Mn}]_{\mathrm{Fe}}}$ is a constant

(2) At equilibrium at any temperature, the oxygen content of the iron is proportional to the FeO content of the (Mn,Fe)O slag. This is sometimes unnecessarily regarded as implying that MnO is insoluble in molten iron, and that oxygen dissolved in iron exists as FeO.

Theoretical derivations of the deoxidation relationship, *i.e.*, the relationship between the quantities of oxygen and manganese in iron in equilibrium with a simple oxide slag, have hitherto involved two steps. First, the equilibrium constant of the reaction

$$[\mathrm{FeO}]_{\mathrm{slag}} + [\mathrm{Mn}]_{\mathrm{Fe}} = [\mathrm{MnO}]_{\mathrm{slag}} + \{\mathrm{Fe}\}$$

is derived, then the data for the solubility of oxygen in iron in equilibrium with FeO are superposed. The two postulates of Körber and Oelsen[8] can be reduced to a more fundamental form; namely, that (i) FeO and MnO together form an ideal solution in all proportions, and (ii) manganese has no effect on the activity of oxygen dissolved in iron.

The following derivation makes use of these two hypotheses, but the method employed is believed to be more flexible than those used hitherto, since it permits the introduction of new experimental data even when these imply departure from the hypotheses. No new data, however, are included, and the discrepancy between the results of the present calculation and those of another published recently[10] illustrates the limitations of thermodynamic calculations based on data that are not of a very high accuracy and which are capable of rather diverse interpretation.

Ferrous oxide melts at 1325° C. and manganous oxide at 1785° C., so that at normal deoxidation temperatures the (Mn,Fe)O slag may be solid or liquid according to its composition. Consequently, two calculations must be made: one for solid, the other for liquid, slags. In the absence of precise information it may be assumed that both the solid and liquid (Mn,Fe)O solutions are ideal, *i.e.*, the solutions are formed with no heats of mixing and with entropies in accordance with those of regular completely disordered solutions.

The equilibria considered are*:

$$\{\mathrm{Mn}_x\mathrm{Fe}_y\mathrm{O}\} = x[\mathrm{Mn}]_{\mathrm{Fe}} + [\mathrm{O}]_{\mathrm{Fe}} + y\{\mathrm{Fe}\} \quad \ldots\ldots(1)$$

$$\langle\mathrm{Mn}_x\mathrm{Fe}_y\mathrm{O}\rangle = x[\mathrm{Mn}]_{\mathrm{Fe}} + [\mathrm{O}]_{\mathrm{Fe}} + y\{\mathrm{Fe}\} \quad \ldots\ldots(2)$$

These equilibria may be compounded of simpler reactions, the summation of whose free energies will yield, by Hess's law, the free energies $\Delta\bar{G}_{(1)}$ and $\Delta\bar{G}_{(2)}$ of reactions (1) and (2).

$$x\{\mathrm{Mn}\} = x[\mathrm{Mn}]_{\mathrm{Fe}} + x\Delta\bar{G}_{(3)} \ldots(3)$$

$$\tfrac{1}{2}(\mathrm{O}_2) = [\mathrm{O}]_{\mathrm{Fe}} + \Delta\bar{G}_{(4)} \ldots(4)$$

$$x\{\mathrm{MnO}\} + \{y\mathrm{FeO}\} = \{\mathrm{Mn}_x\mathrm{Fe}_y\mathrm{O}\} + \Delta G_{(5)} \ldots(5)$$

$$\text{or } x\langle\mathrm{MnO}\rangle + y\langle\mathrm{FeO}\rangle = \langle\mathrm{Mn}_x\mathrm{Fe}_y\mathrm{O}\rangle + \Delta G_{(6)} \ldots(6)$$

$$x\{\mathrm{Mn}\} + \tfrac{x}{2}(\mathrm{O}_2) = x\langle\mathrm{MnO}\rangle + x\Delta G_{(7)} \ldots(7)$$

$$y\{\mathrm{Fe}\} + \tfrac{y}{2}(\mathrm{O}_2) = y\{\mathrm{FeO}\} + y\Delta G_{(8)} \ldots(8)$$

$$x\langle\mathrm{MnO}\rangle = x\{\mathrm{MnO}\} + x\Delta G_{(9)} \ldots(9)$$

$$y\langle\mathrm{FeO}\rangle = y\{\mathrm{FeO}\} + y\Delta G_{(10)} (10)$$

The expressions for the free energies of reactions (1) and (2) are therefore:

$$\Delta\bar{G}_{(1)} = x\Delta\bar{G}_{(3)} + \Delta\bar{G}_{(4)} - \Delta G_{(5)} - x\Delta G_{(7)} - y\Delta G_{(8)} - x\Delta G_{(9)} \ldots(11)$$

$$\Delta\bar{G}_{(2)} = x\Delta\bar{G}_{(3)} + \Delta\bar{G}_{(4)} - \Delta G_{(6)} - x\Delta G_{(7)} - y\Delta G_{(8)} - y\Delta G_{(10)} \ldots(12)$$

The various free-energy values (in calories) and their sources are as follows:

$$\Delta\bar{G}_{(3)} = 4{\cdot}57T\log N_{\mathrm{Mn}} \ (= RT\log_e N_{\mathrm{Mn}}) \quad \ldots\ldots(13)$$

This is an estimated value, assuming no heat of solution and ideal entropy of disordered regular solution.

$$\Delta\bar{G}_{(4)} = -27{,}930 + 4{\cdot}57\,T\log N_{\mathrm{O}} + 6{\cdot}08T \ldots(14)$$

Equation (14) was determined by Dastur and Chipman,[13] whose formula (referring to a fixed concentration of 1 wt.-% of oxygen in iron) has been modified, on the hypothesis that Henry's law is valid, to give direct expression to its dependence upon oxygen concentration.

Richardson's deduction[14] that manganese alters the activity of oxygen in iron by a factor of about 0·9 for a manganese concentration of 0·5% has not been applied, since the numerical value of the change is

* The gaseous state is denoted by ( ), the solid state by < >, liquid by { }, and dilute liquid solution by [ ].
$x + y = 1$.
N_{O} and N_{Mn} denote atomic fractions of oxygen and manganese respectively, in liquid iron.

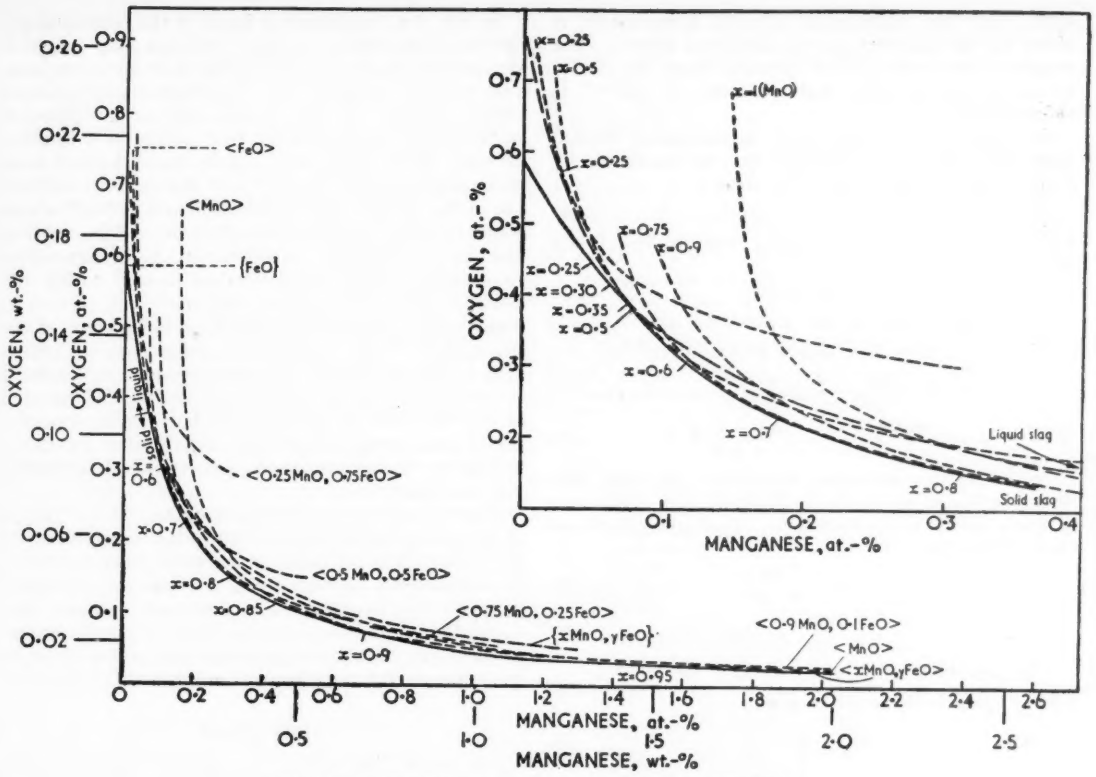

Fig. 4—Deoxidation of iron by manganese, at 1527° C.

not significant in comparison with the errors implicit in the other data used in the calculation.

$$\Delta G_{(5)} \text{ and } \Delta G_{(6)} = 4{\cdot}57\,T(x \log x + y \log y) \quad \ldots\ldots(15)$$

Equation (15) assumes ideal entropy of solution, with no heat of solution.

$$\Delta G_{(7)} = -95{,}400 + 19{\cdot}62T \quad \ldots\ldots(16)$$

Equation (16) was given by Richardson and Jeffes[15] in a review of the literature.

$$\Delta G_{(8)} = -56{,}830 + 11{\cdot}94T \quad \ldots\ldots(17)$$

Equation (17) was determined by Dastur and Chipman.[13]

$$\Delta G_{(9)} = 10{,}700 - 5{\cdot}2T \quad \ldots\ldots(18)$$

Equation (18) was derived by Chipman, Gero, and Winkler.[10]

$$\Delta G_{(10)} = 7300 - 4{\cdot}56T \quad \ldots\ldots(19)$$

Equation (19) was determined by Darken and Gurry.[16]

Two values for the entropy of fusion of FeO may be derived from the work of Darken and Gurry.[16] Chipman *et al.*[10] chose the higher and, by assuming the entropy of fusion of MnO to be equal to that of FeO, derived equation (18). The lower value for the entropy of fusion of FeO from the work of Darken and Gurry[16] has, however, been used in equation (19). The explanation of this apparent anomaly is as follows: If the assumption of Chipman *et al.* is correct, the entropy terms in equations (18) and (19) should be the same. The entropy of fusion of FeO, however, is low compared with that of the average compound having an NaCl-type structure, owing to the high degree of homopolarity of its binding forces. The lowest acceptable value has therefore been selected (equation 19). On the other hand, the entropy of fusion of MnO is probably higher than that of FeO, although still lower than that of the normal NaCl-type compound. In the absence, therefore, of other evidence, the estimate of Chipman *et al.* (equation 18) has been accepted.

For equilibrium between slag and melt, the free-energy changes $\Delta\bar{G}_{(1)}$ and $\Delta\bar{G}_{(2)}$ must be zero.

Considering equations (11)–(19):

$\Delta\bar{G}_{(1)}$ (liquid slags)

$$= 4{\cdot}57T(\log N_O + x \log N_{Mn}) - 4{\cdot}57T(x \log x + y \log y) + 28{,}900 - 5{\cdot}86T + 27{,}870x - 2{\cdot}48Tx = 0 \quad \ldots(20)$$

$\Delta\bar{G}_{(2)}$ (solid slags)

$$= 4{\cdot}57T(\log N_O + x \log N_{Mn}) - 4{\cdot}57T(x \log x + y \log y) + 36{,}200 - 10{\cdot}42T + 31{,}270x - 3{\cdot}12Tx = 0 \quad \ldots(21)$$

The use of these equations can be extended in two ways. Firstly, a series of values of x (and y) may be selected for any temperature, and the corresponding curves giving the relationship between the oxygen and manganese contents of iron in hypothetical equilibrium with the various slag mixtures can be drawn. The slag which is in true equilibrium with a melt of given manganese content is that which corresponds to the lowest oxygen pressure. Accord-

ingly, the true equilibrium at any temperature is given by the envelope to the family of curves. The graphical derivation of the envelope from the family of curves for the solid slag equilibria at 1527° C. is shown in Fig. 4.

Secondly, the envelope may be calculated mathematically. The general method may be illustrated by expressing the equations in the form:

$$a x\xi + b\eta + \phi(x) = 0, \quad \ldots\ldots(22)$$

where $\xi = \log N_{Mn}$, $\eta = \log N_O$, and a and b are constants.

An adjacent curve is given by:

$$a(x + \delta x)\xi + b(\eta) + \phi(x + \delta x) = 0 \quad \ldots\ldots(23)$$

The two curves cross at the point defined by

$$\xi = \frac{b\phi(x + \delta x) - b\phi(x)}{axb - a(x + \delta x)b} \quad \ldots\ldots(24)$$

$$\eta = \frac{ax\phi(x + \delta x) - a(x + \delta x)\phi(x)}{axb - a(x + \delta x)b} \quad \ldots\ldots(25)$$

As δx approaches zero, equations (24) and (25) define the point at which the curves touch. The locus of these points is the envelope. The expressions are then reduced to:

$$\xi = -\frac{1}{a}\frac{d\phi(x)}{dx} \quad \ldots\ldots(26)$$

$$\eta = \frac{1}{b}\left[x\frac{d\phi(x)}{dx} - \phi(x)\right] \quad \ldots\ldots(27)$$

The following equations may now be derived:

(i) *For equilibrium with liquid slag:*

$$\log N_{Mn} = \log x - \log y + \left[\frac{2{\cdot}48T - 27{,}870}{4{\cdot}57T}\right] \quad \ldots\ldots(28)$$

$$\log N_O = \log y + \left[\frac{5{\cdot}86T - 28{,}900}{4{\cdot}57T}\right] \quad \ldots\ldots(29)$$

(ii) *For equilibrium with solid slag:*

$$\log N_{Mn} = \log x - \log y + \left[\frac{3{\cdot}12T - 31{,}270}{4{\cdot}57T}\right] \quad \ldots\ldots(30)$$

$$\log N_O = \log y + \left[\frac{10{\cdot}42T - 36{,}200}{4{\cdot}57T}\right] \quad \ldots\ldots(31)$$

From equations (28)–(31) the relationship between N_{Mn} and N_O in equilibrium with solid or liquid slag may be obtained graphically for any temperature by plotting points corresponding to a series of values of x. The curve for equilibrium between metal and liquid slag at 1527° C., shown in Fig. 4, was derived in this way. It will be seen that the compositions of the solid and liquid slags at the point of intersection of the two envelopes are different, the difference corresponding to the separation between the liquidus and solidus lines in the FeO/MnO equilibrium diagram at this temperature. The particular values obtained for the compositions of the coexisting solid and liquid slags are a direct consequence of the assumptions of ideality made in the derivation of the equations.

A study of the two equations for each envelope reveals that they consist of the two relationships previously mentioned, *i.e.*, the equilibrium between the slag composition and the manganese content of the metal, and the equilibrium between the oxygen content of the melt and the FeO content of the slag. These relationships cannot be resolved so simply if data for the change in activity of oxygen due to the deoxidizing element in the melt, or for the formation of a non-ideal slag solution, are introduced.

In Fig. 3 a comparison is made of the relationships, derived from various sources, between slag composition and manganese content of the melt, for a temperature of 1527° C. (1800° K.). The discrepancy between curves *d* and *e* is the result only of a difference in the values taken for the free energy of formation of solid MnO. Both values have been derived from the same original source,[17] but the present authors are of the opinion that Richardson and Jeffes,[15] whose value has been used in calculating curve *d*, have given the more detailed consideration to temperature dependence. Each of the values is well within the possible error of the other, and this error, of course, forms only a part of the overall probable error of the calculation. This consideration provides some indication of the limitations of thermodynamic calculations of this type. The accuracy of the derived information is very sensitive to errors in the basic data, since the use of free-energy values to give equilibrium constants, activities, or concentrations, involves an antilogarithmic manipulation.

The closeness of adjacent members of the family of curves shown in Fig. 4, both at low oxygen and at low manganese contents of the melt, may be noted. It is indicative of very small free-energy differences between the hypothetical equilibrium systems, and suggests that very small quantities of a fourth element at these extremes of composition may have a profound influence on the equilibrium composition of the slag.

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Subsidiary Paint Tests at Birmingham: Final Report

By J. C. Hudson, D.Sc., F.I.M.

SYNOPSIS

An exposure test over 15 years has confirmed that surface preparation is the most important single factor contributing to successful protection of iron and steel, by means of paint, against atmospheric corrosion. The average life of 2-coat painting schemes was nearly six times greater on a pickled surface than on a weathered and wirebrushed one. The best of the painting schemes tested—two coats of micaceous iron ore paint—protected pickled wrought iron perfectly for the whole of the 15 years; even better results should be obtained by using a red lead priming paint under a finishing coat of micaceous iron ore paint. Heating a weathered surface, so as to dehydrate the rust, improved the performance of painting schemes but this was still greatly inferior to that on the descaled and unrusted surface obtained by pickling.

THIS is the final report on a subsidiary series of exposure tests on the protection of ferrous metals by means of painting schemes, which was continued for 15 years.*

At the time the tests were started (1932), the importance of the effect of surface preparation for painting on performance of painting schemes applied to iron and steel had not been established, and the experimental programme was mainly designed to obtain information on this point.

EXPERIMENTAL DETAILS

Materials Tested

Forty-two specimens, each 4 in. × 2 in. × $\frac{1}{8}$ in., were exposed; 36 of these were of Staffordshire wrought iron, three were of mild steel, and three were of ingot iron. The ingot iron carried an annealing scale. Analyses of the materials are given in Table I.

Table I

ANALYSIS OF THE BASIS MATERIALS

Material	Analysis, %				
	C	Mn	Si	P	S
Ingot iron	0·014	0·035	0·03*	0·008	0·026
Mild steel	0·25	0·56	0·031	0·040	0·037
Wrought iron	0·018	0·035	0·150	0·205	0·018

* Typical value for this type of material

The Paints

The compositions of the seven paints used, expressed as percentages by weight, were:

Black bitumen

Natural bitumen	60
Stand oil	24
Tung oil	13
Neutral resin	3

(This is the composition of the dry paint film.)

Lead chromate

Basic lead chromate ($PbCrO_4$, 56·9%; PbO, 40·6%; CaO, 1·4%)	66
Boiled linseed oil	16
Refined linseed oil	16
Liquid driers	2

Micaceous iron ore

Micaceous iron ore	66
Drying oil and gums	18
Volatile solvent	16

Red lead

Red lead (Pb_3O_4, 95% minimum)	81
Boiled linseed oil (Pb, 0·15%; Mn, 0·05%)	8
Refined linseed oil	8
White spirit	3

Red oxide

Iron oxide (Grade *A*, type *M* of BS 272 Fe_2O_3, 76%)	65
Boiled linseed oil	14
Refined linseed oil	14
White spirit	4
Liquid driers	3

Red oxide plus zinc chromate

Indian red	53
Zinc chromate	16
Boiled linseed oil	13
Refined linseed oil	13
Liquid driers	3
White spirit	2

White lead

White lead (dry, to BS 239)	78
Pale boiled linseed oil	12
Refined linseed oil	6
Turpentine	4

All seven paints were tested as 2-coat systems. In addition, the black bituminous, micaceous iron ore, and red oxide paints were used as single finishing coats over single priming coats of lead chromate, red lead, or white lead paint.

* Second Report of the Corrosion Committee, *Special Report No.* 5, pp. 266–275, 1934; Third Report, *ibid.*, *Special Report No.* 8, pp. 201–205, 1935; Fourth Report, *ibid.*, *Special Report No.* 13, pp. 195–201, 1936; Fifth Report, *ibid.*, *Special Report No.* 21, pp. 267–275, 1938: The Iron and Steel Institute.

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Surface Preparation for Painting

Two wrought-iron specimens were painted with red oxide paint over the intact millscale, and seven wrought-iron specimens were entirely descaled by pickling in 15% sulphuric acid solution at 45° C., followed by scrubbing under water, drying, and wirebrushing. Otherwise all the specimens were prepared for painting by exposure to the weather in the suburbs of Birmingham for 39 days during March and April, 1932, followed by wirebrushing by hand. This treatment resulted in an average removal of 24, 62, and 48% of the oxide scale for the wrought iron, the mild steel, and the ingot iron, respectively.

To study the effects of dehydrating the rust and removing any soluble salts in it, 11 of the weathered wrought-iron specimens were heated to 200° C., wirebrushed, and painted while warm ; four of these specimens were thoroughly washed in hot water before being heated.

Table II

PARTICULARS OF PAINTING AND RESULTS

Painting Scheme		Life of Painting Scheme to Failure, yr.
Paint	Surface Preparation*	
Black bituminous (2 coats)	p	13·1†
	w	2·6
	wh	2·2
Lead chromate (2 coats)	p	14·5†
	w	2·7
	wh	7·5
Micaceous iron ore (2 coats)	p	15·0†
	w	0·6
	wh	0·6
	wwh	1·1
	w‡	0·6
	w§	0·6
Red lead (2 coats)	p	13·1†
	w	1·1
	wh	5·9
Red oxide (2 coats)	p	8·1†
	r	5·3
	r	5·6
	w	1·8
	wh	2·8
	wwh	2·2
	w‡	0·6
	w§	0·6
Red oxide plus zinc chromate (2 coats)	p	9·6†
	w	3·7
	wh	5·3
	wwh	6·3
White lead (2 coats)	p	7·0
	w	2·2
	wh	1·7
	wwh	2·7
	w‡	1·1
	w§	1·1
Lead chromate (1 coat) and :		
Black bituminous (1 coat)	w	4·0
Micaceous iron ore (1 coat)	w	2·2
Red oxide (1 coat)	w	2·2
Red lead (1 coat) and :		
Black bituminous (1 coat)	w	2·7
Micaceous iron ore (1 coat)	w	1·1
Red oxide (1 coat)	w	5·0
White lead (1 coat) and :		
Black bituminous (1 coat)	w	4·6
Micaceous iron ore (1 coat)	w	1·8
Red oxide (1 coat)	w	4·6

* p = pickled ; r = as-rolled ; w = weathered ; wh = weathered and heated ; wwh = weathered, washed, and heated
† Back surface had not failed after 15 years' exposure
‡ Ingot-iron specimens
§ Mild-steel specimens

Painting

Two coats of paint were applied by brush to each specimen, under good conditions in the laboratory, during April and May, 1932. Nine days elapsed between the two coats, and 16 days between the second coat and exposure. A list of the painting schemes tested is given in Table II. Each coat of paint was weighed.

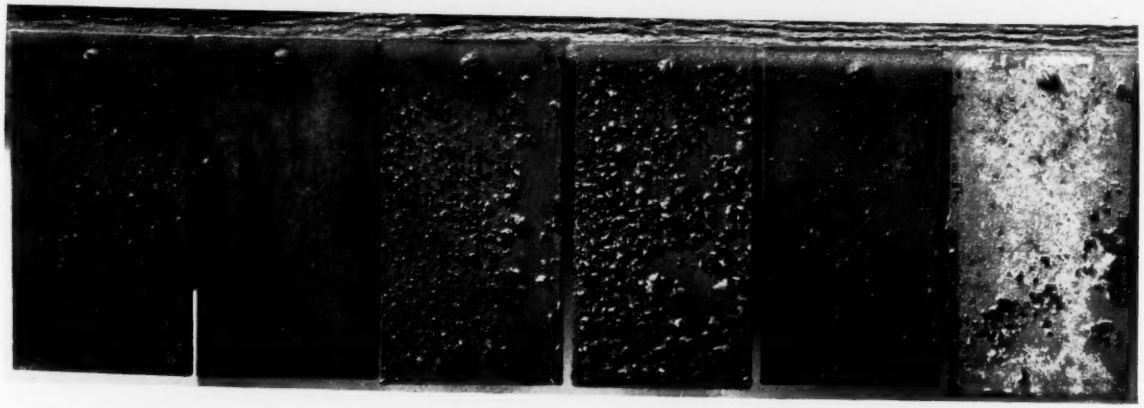
For seven 2-coat systems of the same paint, the average value for the total thickness of the dry paint film, calculated from the weights of paint applied, varied from 1·6 to 2·4 mils. It is an interesting fact that rather more paint was applied to the pickled wrought-iron specimens than to the weathered ones, no doubt because of the porosity of a pickled wrought-iron surface. Slightly less paint was applied to heated weathered surfaces because of the effect of temperature on spreading rate. These slight variations in paint film thickness would not, however, affect the conclusions drawn from the tests.

Exposure

The specimens were exposed vertically in the suburbs of Birmingham, in May 1932, at 5 ft. from the ground, facing approximately 60° west of south. The severity of the atmospheric conditions may be gauged from the fact that the rate of corrosion at the site, over five years, of a pair of reference specimens of bare pickled ingot iron, was 1·68 mils per year. This figure is identical with that observed in a marine atmosphere at Calshot, and is approximately half the value expected in an industrial atmosphere, such as Sheffield.

Inspections

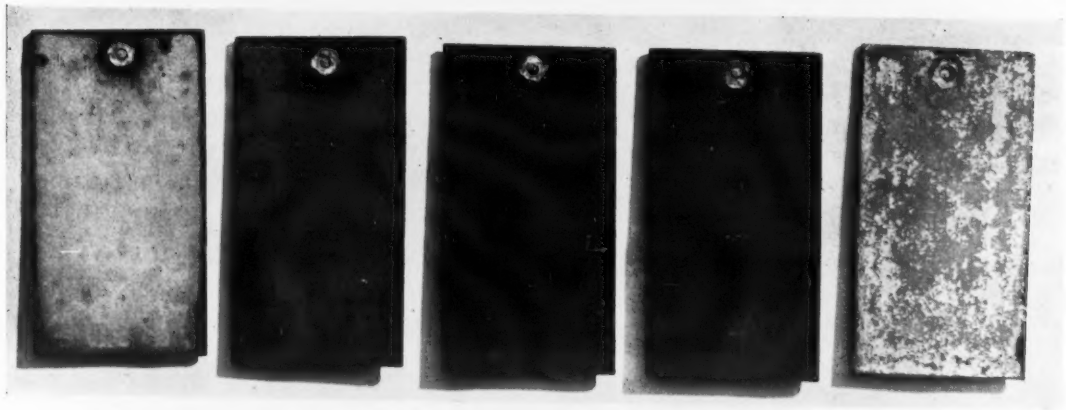
Exposure was continued until January 1948, when the last specimens were removed after 15 years' exposure, a little exposure time having been lost for various reasons. Throughout the test the condition of the paint on the front and back of each specimen was recorded in a standard manner at suitable intervals. The simplest method of presenting the results is to use the observations to determine the life, in years, of each of the 42 painting schemes (*i.e.*, combination of metal, surface preparation, priming coat, and finishing coat) to a standard degree of breakdown. The degree of breakdown selected corresponds approximately to 0·1–0·2% of surface rusted, and therefore represents a more severe standard than that recently adopted by Joint Technical Panel J/P1 of the Protective Coatings Sub-Committee,



No. 22 No. 23 No. 24 No. 25 No. 21 No. 27

No. 22—Micaceous iron ore paint over weathered and heated wrought iron
No. 23—Micaceous iron ore paint over pickled wrought iron
No. 24—Micaceous iron ore paint over weathered and heated ingot iron
No. 25—Micaceous iron ore paint over weathered mild steel
No. 21—Micaceous iron ore paint over weathered, washed and heated wrought iron.
No. 27—White lead paint over weathered ingot iron.

Fig. 1—Representative specimens after three years' exposure ×½



No. 6 No. 9 No. 17 No. 23 No. 35

No. 6—Lead chromate paint
No. 9—Red Oxide plus zinc chromate paint
No. 17—Black bituminous paint
No. 23—Micaceous iron ore paint
No. 35—Read lead paint

Fig. 2—Specimens after ten years' exposure ×½

[Hudson
To face p. 154

who consider that structures should be repainted when 0·2–0·5% of rust has developed.*

Values for the durability of the painting schemes deduced in this way are given in Table II ; they take into account the gradings both on the front and on the back surfaces. These figures may be supplemented by a few additional quantitative observations made during exposure.

Small pinhead blisters became visible within a fortnight on all specimens except those painted over the intact millscale or in the pickled condition. The blistering rapidly became more pronounced, and on many specimens the paint film burst and began to flake off locally within a year. Failure on weathered surfaces was more pronounced and more rapid for ingot iron and mild steel than for wrought iron. It was also evident that the preliminary heating, with or without washing, given to some of the weathered wrought-iron specimens had improved performance.

After five years the deterioration of the painting schemes on weathered surfaces was so severe that 21 of them were removed from test. This left only 12 specimens of this type, and, of these, four had been weathered and heated and two had been weathered, washed, and heated. Moreover, with a single exception, no weathered specimen that had received a non-inhibitive priming coat, *i.e.*, black bituminous, micaceous iron ore, or red oxide paint, had survived.

The two as-rolled and painted specimens began to be visibly inferior to the seven pickled and painted specimens after about three years' exposure. These seven remained in practically perfect condition for rather more than another year, when the two specimens painted with white lead and red oxide paint, respectively, began to show signs of deterioration. The specimen painted with white lead was the worse ; after five years this paint was badly discoloured, and there were about 50 pinhead failures on its front surface (8 sq. in.).

After seven years the five painting schemes, other than white lead paint and red oxide paint, applied to a pickled surface were in perfect condition. Eleven other specimens had, however, deteriorated so much that they were then removed from test. Ten of these had been weathered ; the eleventh was the pickled specimen painted with white lead paint. This left four specimens prepared for painting by methods other than pickling : a single as-rolled specimen painted with red oxide paint, two specimens painted with lead chromate and red lead paints (after having been weathered and heated), and a specimen painted with red oxide and zinc chromate paint after weathering, washing, and heating. These four specimens and the pickled specimen painted with red oxide paint showed appreciable signs of breakdown, and were removed after eight years, leaving five pickled and painted specimens.

Breakdown developed slowly, but after 11 years the specimen painted with red oxide plus zinc chromate paint had passed the point of failure on the front surface, on which there was about 10% of rust staining. At this stage the micaceous iron ore paint showed a slight superiority over its rivals, which it retained until the end of the test. By then, all the other painting schemes had failed on the fronts. The failure of the specimen painted with red lead was abrupt ; from the early stages of exposure this paint film had shown the lamellar exfoliation typical of red lead in linseed oil paints (*see* Fig. 2), and had presumably suffered considerable thinning thereby. Shortly after 11 years' exposure, numerous pinhead rust spots developed through the paint all over the front surface, and failure occurred.

Photographic records were taken of the progress of deterioration, and two typical photographs are reproduced here. Figure 1 shows six specimens at half natural size after three years ' exposure. The contrast between the breakdown of the paint films on the weathered surfaces and the excellent behaviour of the micaceous iron ore paint on the pickled surface is striking. Specimen No. 21, prepared by weathering, washing, and heating, was in better condition than specimen No. 22, prepared by weathering and heating only ; and both specimens behaved better than specimen No. 20 (not shown), prepared by weathering but without washing or heating.

* " Painting of Structural Steelwork." Second Interim Report of Joint Technical Panel J/P1, 1949 : The British Iron and Steel Research Association.

Table III

METHOD OF SURFACE PREPARATION FOR PAINTING

Painting Scheme (Two Coats)	Life of Painting Scheme, yr.		
	Over Weathered Surface	Over Pickled Surface	Over Weathered and Heated Surface
Black bituminous	2·6	13·1*	2·2
Lead chromate	2·7	14·5*	7·5
Micaceous iron ore	0·6	>15·0	0·6
Red lead	1·1	13·1*	5·9
Red oxide	1·8	8·1*	2·8
Red oxide and zinc chromate	3·7	9·6*	5·3
White lead	2·2	7·0	1·7
Average	2·1	>11·5	3·7

* Back surface had not failed after 15 years' exposure

Table IV

EFFECT OF DEHYDRATING THE RUST ON WEATHERED SURFACES

Painting Scheme (Two Coats)	Life of Painting Scheme, yr.		
	Over Weathered Surface	Over Weathered and Heated Surface	Over Weathered, Washed, and Heated Surface
Micaceous iron ore	0·6	0·6	1·1
Red oxide	1·8	2·8	2·2
Red oxide and zinc chromate	3·7	5·3	6·3
White lead	2·2	1·7	2·7
Average	2·1	2·6	3·1

XUM

Table V

EFFECT OF INHIBITIVE PRIMING PAINTS

Priming Paint	Life of Painting Scheme on Weathered Specimens, yr.			
	Finishing Paint			
	Black Bituminous	Micaceous Iron Ore	Red Oxide	Average
Non-Inhibitive				
Black bituminous	2·6	...	...	
Micaceous iron ore	...	0·6	...	1·7
Red oxide	...	...	1·8	
Inhibitive				
Lead chromate	4·0	2·2	2·2	
Red lead	2·7	1·1	5·0	2·9
White lead	4·6	1·8	2·2	

The condition, after ten years' exposure, of the five pickled and painted specimens that survived until the end of the test is shown in Fig. 2. The worst area of breakdown on specimen No. 17 may be due to damage.

RESULTS

The results of the experiments are given in Tables III, IV, and V, which show the effects on the durability of the painting scheme of (i) surface condition, (ii) treating and washing the rust on a weathered surface, and (iii) priming coats of inhibitive paints.

CONCLUSIONS

(1) Correct surface preparation has a very marked effect on the durability of a painting scheme (*see* Table III). The overall average life to failure is nearly six times greater for pickled surfaces than for weathered surfaces.

(2) The best painting scheme in this particular test has protected wrought iron perfectly for 15 years. When it is considered that only two coats of paint, with a total dry-film thickness of only 2·2 mils, were applied, it seems reasonable to conclude that the maximum potentialities of painting schemes for the protection of steel structures are far from being realized under industrial conditions, where the effective life of 3- or 4-coat painting schemes is reported to vary from two to seven years.*

(3) Heating a weathered surface to dehydrate the rust has proved beneficial. The average durability of the painting schemes has been increased from 2·1 to 3·7 years, or by nearly 80%. This confirms the value, in this respect, of the flame-cleaning process, which has been introduced since these tests were begun.

(4) Washing the surface to remove soluble products from the rust has led to a further slight increase in durability (*see* Table IV).

* Fifth Report of the Corrosion Committee, p. 344, *Special Report No.* 21, 1938 : The Iron and Steel Institute.

Table VI

EFFECT OF THE BASIS IRON OR STEEL (WEATHERED SURFACES)

Basis Material	Life of the Painting Scheme on Weathered Specimens, Yr.			
	Micaceous Iron Ore	Red Oxide	White Lead	Average
Ingot iron	0·6	0·6	1·1	0·8
Mild steel	0·6	0·0	1·1	0·8
Wrought iron	0·6	1·8	2·2	1·5

(5) The use of an inhibitive priming paint (*i.e.*, a paint containing pigments that will tend to prevent corrosion as a result of chemical action on the steel surface) is advantageous (*see* Table V). The average life of 2-coat painting schemes of black bituminous, micaceous iron ore, and red oxide paints was 1·7 years, but when these paints were applied as single finishing coats over priming coats of three inhibitive paints, lead chromate, red lead, and white lead, the average life of the painting schemes rose to 2·9 years.

(6) The best result on weathered surfaces, a life of 5·0 years, was obtained with the well-tried and commonly used combination of red lead priming paint and red oxide finishing paint. Table II, however, shows that where painting schemes are applied to a correctly prepared surface, such as that obtained by pickling, the advantages of using inhibitive primers are considerably reduced. The maximum life observed in these tests was obtained when a priming coat of micaceous iron ore paint was overpainted with the same paint, although micaceous iron ore has no inhibitive properties.

Nevertheless, it would be wrong to conclude that there is no advantage in using inhibitive priming paints for correctly prepared, descaled, and unrusted iron or steel surfaces, because all the painting schemes tested over a pickled surface consisted of two coats of the same paint. It is reasonable to assume, for instance, that the combination of a red lead priming paint with a finishing coat of micaceous iron ore paint would have a life exceeding that of two coats of micaceous iron ore paint. Although it is not the best practice to use finishing coats of red lead paint, owing to the gradual disintegration of the paint itself on weathering, the painting scheme consisting of two coats of this paint had a surprisingly long life in these tests.

(7) The average life of the painting schemes on weathered specimens of mild steel or ingot iron was 0·8 years in both cases, compared with 1·5 years for wrought iron (*see* Table VI). This result is not to be taken as typical of the three materials but illustrates the differences that may be caused by different types of millscale when weathering is used as a method of surface preparation.

Acknowledgments

The author is indebted to his former colleague, Dr. T. A. Banfield, and to the Photographic Section of B.I.S.R.A. for help in preparing the illustrations.

Tensile and Impact Properties of Iron and Some Iron Alloys of High Purity

By W. P. Rees, M.Sc., B. E. Hopkins, M.Sc., and H. R. Tipler, B.Met.

SYNOPSIS

The tensile and impact properties of high-purity iron and of iron–manganese, iron–carbon, and iron–carbon–manganese alloys, at various temperatures covering the tough to brittle transition, are discussed. The technique used to carry out tests at low temperatures is described. Attention is drawn to the two types of brittleness, intergranular and cleavage, that can occur in iron. The evidence presented indicates that oxygen is effective in promoting intergranular brittleness. The oxygen content below which intergranular brittleness is not encountered is less when the iron is made in one furnace than in another. The incidence of intergranular brittleness is also affected either by grain size or by some other factor resulting from the treatment used to obtain coarse grains, *i.e.*, straining and heating below the transformation temperature. Manganese and carbon plus manganese, are shown to lower the temperature of transition from tough to brittle fracture, and to raise the cleavage strength. The effect of carbon in raising the transition temperature may possbly be explained by the rise in yield stress.

An understanding of the properties of ferrite is necessary for a proper appreciation of the behaviour of all ferritic steels. The study of the factors underlying toughness and brittleness in ferritic steels is one of the main objects of this work. Accordingly, the transition from the tough to the brittle condition as the materials were progressively cooled has been examined by means of tensile and notched-bar impact tests. Every effort has been made to reduce to the lowest practicable limit all impurities other than those under investigation: in general, no undesired element has been present in concentration greater than 0·01%, and the concentrations of non-metallic impurities have been considerably lower.

A technique for the production of iron and iron alloys of high purity, on a scale large enough to enable a comprehensive series of mechanical tests to be undertaken, has already been described.[1] In the present paper the properties of iron, and of a series of iron–manganese alloys containing up to 5% of manganese, made on the 25-lb. scale, are described. The effects of the addition of carbon to iron and to iron–manganese alloys containing up to 2% of manganese are also discussed. Although an investigation of the influence of oxygen at this stage was not planned, the importance of very small variations of the oxygen content of the materials became apparent during the course of the work.

Before the 25-lb. induction furnace became available, some preliminary work was carried out on irons made in a 6-lb. induction furnace, and the properties of irons made in both furnaces are compared.

PREPARATION OF MATERIALS

The general procedure in preparing high-purity iron and alloys was to melt oxidized Swedish iron *in vacuo*, treat the melt with well-dried hydrogen at atmospheric pressure until the oxygen was removed, lower the pressure to remove the majority of the hydrogen, and cast the metal in a chill mould without exposure to air. The ingots were octagonal, $2\frac{3}{4}$ in. across the flats and $10\frac{1}{2}$ in. long, and were hot-rolled to $\frac{5}{8}$-in. dia. bars, which were normalized by heating to 950° C. for a short time and cooling in air.

When alloys were being prepared, additions to the iron were normally made after it had been deoxidized by the hydrogen, and if the added element contained oxygen the hydrogen treatment was prolonged to effect deoxidation of the alloy. It frequently happened that the alloying elements could be obtained in a state of high purity, with the exception of oxygen (although this may only have been surface oxide which was difficult to remove completely beforehand, as in the case of electrolytic manganese). Carbon was added immediately before pouring, after reducing the hydrogen pressure to 5 cm. of Hg, because some attack on the alumina crucible occurred, resulting in the introduction of a little aluminium into the alloy. The electrolytic manganese had the following main impurities:

C, %	Si, %	S, %	P, %	Ni, %	Cu, %	Fe, %
0·008	0·003	0·024	0·002	<0·001	<0·001	0·001

The carbon used was Hilger H.S. electrodes.

The procedure for melting in the 6-lb. furnace was generally similar, except that the reduction of the oxygen content was carried out under a reduced pressure of hydrogen (16 cm. of Hg), and the metal was not cast but was allowed to solidify in the crucible. Because of the lower hydrogen pressure, necessitated by the power characteristics of the furnace, the removal of oxygen was much slower in the 6-lb. furnace, and treatment with hydrogen for 12 hr. was necessary to reduce the oxygen content of the iron to below 0·001%.

TENSILE AND IMPACT TESTING AT LOW TEMPERATURES

The transition from ductile to brittle behaviour in iron alloys frequently occurs below room temperature, and tensile and impact tests had therefore to be carried out at low temperatures. The apparatus developed

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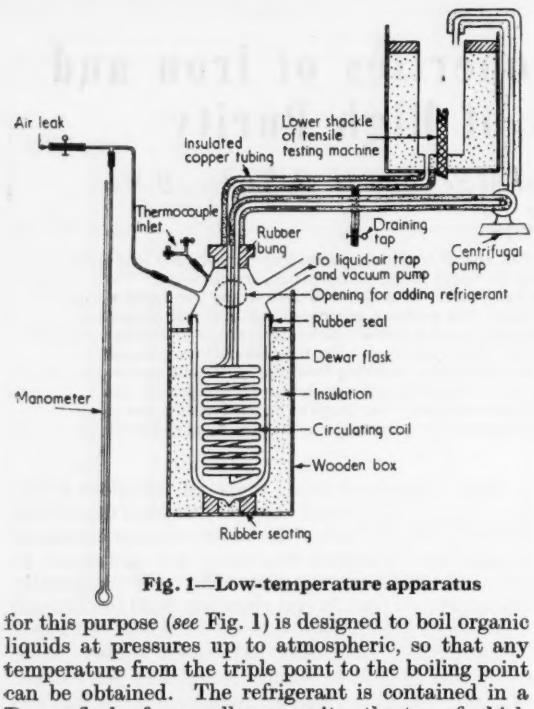

Fig. 1—Low-temperature apparatus

for this purpose (*see* Fig. 1) is designed to boil organic liquids at pressures up to atmospheric, so that any temperature from the triple point to the boiling point can be obtained. The refrigerant is contained in a Dewar flask of one gallon capacity, the top of which is closed by a conical metal cover and rubber bung. The seal between the flask and the metal cover is made by means of a rubber sleeve. A 1½-in. dia. outlet pipe from the metal cover passes through a large liquid air trap to a rotary vacuum pump with a pumping capacity of approximately 20 cu. ft./min. The pressure, and hence the temperature of the refrigerant, can be adjusted by an air leak into the flask. The liquid air trap serves to reduce the back-pressure due to the solubility of the vapour of the organic refrigerant in the oil of the vacuum pump.

Since it is necessary to carry out the tensile and impact tests at atmospheric pressure, the low temperature in the Dewar flask is 'transferred' to an open cylindrical container by means of a suitable liquid circulated, by a small centrifugal pump, through a copper coil immersed in the flask and then round the test piece. The apparatus is well insulated.

The extension of the lower shackle of the tensile-testing machine passes through the bottom of the container of cold liquid which surrounds the test piece. The equipment is on a trolley which, when carrying out impact tests, is moved to the Charpy-type impact-testing machine. Impact test pieces 55 mm. long × 10 mm. square with an Izod-type **V** notch are cooled in the container and transferred to the machine for testing. The increase in temperature at the base of the notch during transfer from the cold liquid is very small (about 1° at − 70° C.) in the few seconds taken to perform the operation, and allowance is made for this.

The system of boiling liquids at reduced pressures has the advantage of enabling any temperature between the boiling point and the triple point to be obtained. Suitable liquids, with their useful ranges, are :

	Boiling Point at Atmospheric Pressure, °C.	Triple Point, °C.	Freezing Point, °C.
Methyl chloride	−24·2	−97·7	
Ethylene	−103·9	−169	
Acetone	+56		−94·6
Methane	−164	−183·1	
Dichloro-difluoro-methane (Freon 12 or Arcton 6)	−29·8	−155	
Monochloro-trifluoro-methane (Freon 13 or Arcton 3)	−81·5	−181·6	
Isopentane*	+28		−159·9
Nitrogen	−195·8	−209·9	

*Useful as a circulating liquid over a large range of temperature.

Temperatures down to − 78° C. can also be obtained conveniently by cooling acetone with solid carbon dioxide, although a little skill is needed in keeping intermediate temperatures constant. Fixed temperatures, such as that of boiling liquid nitrogen, are easily obtained by pouring the liquid into the container surrounding the test piece.

A copper–constantan thermocouple connected to a potentiometer is used to measure the temperature in the Dewar flask and that of the liquid circulating round the test piece.

PROPERTIES OF HIGH-PURITY IRON

The chemical analyses of five irons made in the 25-lb. furnace are given in Table I. The variations in carbon and oxygen contents of the first four irons 18*AF*2, 18*AF*3, 21*AF*1, and 22*AF*1, enable an estimate of the

Table I

CHEMICAL ANALYSES OF FIVE IRONS MADE IN THE 25-lb. FURNACE

Element, %	18*AF*2	18*AF*3	21*AF*1	22*AF*1	53*AF*1
Carbon	0·0025	0·0058	0·0026	0·0082	0·0025
Silicon	0·009	0·004	0·007	0·010	0·003
Manganese	0·004	0·004	0·008	<0·001	<0·005
Sulphur	0·0055	0·003	0·004	0·001	0·0046
Phosphorus	<0·001	<0·001	0·0015	<0·001	0·001
Nickel	0·007	0·007	0·007	0·006	0·007
Chromium	0·002	0·002	<0·001	0·001	0·001
Copper	0·007	0·007	0·007	0·007	0·005
Aluminium	<0·001	<0·001	<0·001	0·001	0·004
Oxygen	0·016	0·0008	0·0037	0·0018	0·001
Nitrogen	0·003	$0·002_3$	$0·001_5$	$0·001_2$	0·001
Hydrogen	<0·000005	<0·000005	<0·000005	<0·000005	<0·000005

Table II

TENSILE PROPERTIES OF FIVE IRONS IN THE NORMALIZED CONDITION

Property	18AF2 6 grains/mm.			18AF3 13·3 grains/mm.			21AF1 4·5 grains/mm.			22AF1 13·2 grains/mm.			53AF1 7·7 grains/mm.		
	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C
Lower yield, tons/sq. in.	8·0	17·2	..	11·1	18·6	37·7*	6·7	15·3	..	11·2	18·3	..	7·95	15·8 14·9	37·6*
Ultimate tensile strength, tons/sq. in.	17·3	21·6	32·3	18·3	22·6	44·4	16·6	20·3	28·9	18·7	22·7	45·2	17·4	21·2 20·8	42·7
Elongation on $4\sqrt{\text{Area}}$, %	52	50	1	48	50	2	45	53	2	52	56	4	53	81†	4
Reduction in area, %	90	80	1	94	94	2½	90	90	1½	92	87	3	92	66 91	5
Rate of strain-hardening, tons/sq. in. per unit strain	18·8	23·2	.	19·2	21·8		approx. 17·2	approx. 19·7		18·7	22·6		18·2	18·7	
Fracture stress at −196° C.	approx.		32·7			45·6			29·3			46·8			45·0
Fracture	Ductile	Ductile	Mostly cleavage, some inter-crystalline	Ductile	Ductile	Cleavage	Ductile	Ductile	Mostly cleavage, some inter-crystalline	Ductile	Ductile	Cleavage	Ductile	Ductile	Cleavage

* 0·5% proof stress, no yield
† This test piece necked in two regions, giving an abnormally high elongation

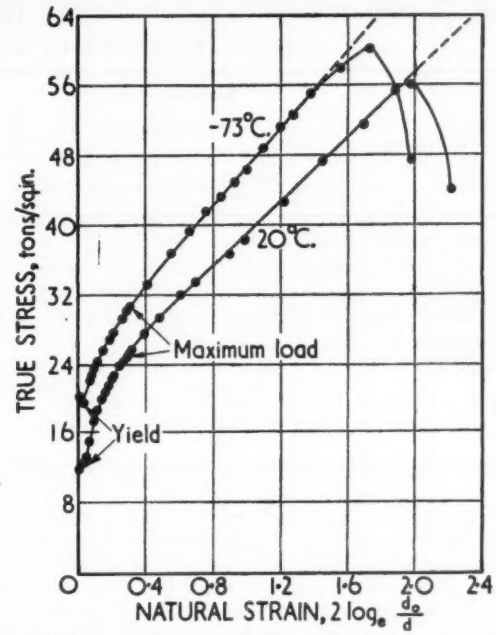

Fig. 2—True-stress/natural-strain tensile curves for iron 22AF1

effect of small quantities of these elements to be made, by comparision with the later iron 53AF1 in which all the elements have been reduced to low levels. The oxygen content of iron 18AF2 was well above the solubility limit in ferrite, so that the microstructure shows globules of iron oxide (Fig. 4). The microstructures of the other irons were alike; a typical example is given in Fig. 5, which shows iron 18AF3.

Tensile tests were carried out over a range of temperatures, in a hydraulically operated testing machine. The 0·282-in. dia. test pieces had a gauge length of 1 in. with ¼-in. B.S.W. rolled threads. The diameter of the test piece was measured continuously during the course of the test, enabling true-stress/natural-strain* curves to be drawn for each material.

Examples of the true-stress/natural-strain curves obtained are given for iron 22AF1, at room temperature and at −73° C., in Fig. 2, and general tensile properties of all five irons are given in Table II. The slope of the straight portion of the true-stress/strain curve beyond the maximum load is an index of the work-hardening capacity, and the curves show that, at the same temperature, all five irons work-hardened at about the same rate, but the rate of work-hardening increased with decrease in testing temperature. The departure of the plotted points from the straight line, towards the end of the test, is believed to be the result of slightly non-uniform necking (rumpled surface) because of the coarseness of the grains.

Table II shows that all the irons in the normalized

* Natural strain is $2\log_e d_o/d$, where d_o is the original diameter of the test piece and d is the minimum diameter of the stressed test piece.

Table III

TENSILE PROPERTIES OF IRON 21*AF*1 AT THREE GRAIN SIZES

Property	Normalized 950° C. 4·5 grains/mm.			2% Elongation, 4 hr. at 900° C., Air-cooled 0·55 grains/mm.			3% Elongation, 4 hr. at 900° C., Air-cooled 0·1–0·3 grains/mm.		
	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C.	Room Temp.	−73° C.	−196° C.
Lower yield, tons/sq. in.	6·7	15·3	..	Not detected	17·7	..	Not detected	12·4	..
Ultimate tensile strength, tons/sq. in.	16·6	20·3	28·9	13·1	19·2	27·4	13·0	13·8	28·2
Elongation on $4\sqrt{\text{Area}}$, %	45	53	2	43	40	2	44	38	1
Reduction in area, %	90 approx.	90 approx.	1½	>95	95 approx.	0	>95	100	0
Fracture stress at −196° C.			29·3			27·4			28·2
Fracture	Ductile	Ductile	Mostly cleavage, some inter-crystalline	Ductile	Ductile	Mostly cleavage, some inter-crystalline	Ductile	Ductile chisel-edge	Mostly cleavage, some inter-crystalline

condition were exceedingly ductile at room temperature and at − 73° C., the reduction of area usually being more than 90%. The test pieces reduced in area at the neck to such an extent, and the testing load fell to such a low value, that it was not possible to obtain a reasonable figure for the true breaking stress. The irons had a yield point down to − 73° C. but were brittle at − 196° C., at which temperature no yield point was found although a small amount of deformation occurred. The transition from ductile to brittle behaviour in tension therefore lies a little above − 196° C. The fractures at − 196° C. were of the cleavage type, but a little intergranular failure was also apparent in irons 18*AF*2 and 21*AF*1. It is significant that iron 21*AF*1 had an oxygen content of 0·0037%, which has always been considered on the high side for a high-purity iron. Iron 18*AF*2, with an oxygen content of 0·016%, is an example of an oxygen-containing iron. The proportions of the fractures of irons 18*AF*2 and 21*AF*1 which broke in an intergranular manner were quite small, and were not at first detected. They were found on re-inspection, when it was realized that they might be there after investigation of another factor (namely, grain size) that appears to affect the incidence of intergranular brittleness.

Two coarse grain sizes were obtained in iron 21*AF*1 by straining normalized bars 3% and 5% in a tensile testing machine and heating at 900° C. for 4 hr., followed by cooling in air. The results of tensile tests on the material in these conditions at room temperature, at −73° C., and at −196° C., are given in Table III. In the normalized condition, the material had a yield point at room temperature, but in the two coarse-grained conditions a yield was evident only at −73° C. It appears, therefore, that non-occurrenec of a yield point in iron at room temperature is not a guarantee that the factors giving rise to the yield phenomenon are entirely absent, because such a material may exhibit a yield if tested at a lower temperature.

The low yield and ultimate stresses of iron 21*AF*1 in the coarsest-grained condition are explained by the small number of grains present in the test pieces. At − 73° C. the test piece pulled down to a chisel edge, giving a reduction in area of 100%, because there was only one grain in the cross-section in this region. At − 196° C. the material in the three grain sizes was completely brittle, and the ultimate stress was approximately the same within the limits 27·4–28·9 tons/sq. in. The brittle fractures were mostly cleavage, but the areas that broke in an intergranular manner were considerably more evident in the two coarse-grained test pieces (where they appeared mostly at the periphery) than in the normalized test piece. The brittle strengths at − 196° C. of iron 18*AF*2 in the normalized condition (32·7 tons/sq. in) and of iron 21*AF*1 in three grain sizes (27·4–29·3 tons/sq. in.) were all much lower than for the other irons (45·0–46·8 tons/sq. in.); comparison, especially with iron 53*AF*1, leads to the conclusion that this low strength must be due to intergranular weakness resulting from the higher oxygen contents.

The evidence that grain size affects the incidence of intergranular brittleness is strong in the results of Charpy impact tests, which will now be discussed.

The impact-value/temperature curves for the five irons in the normalized condition are given in Fig. 3. A feature of these curves is the sharpness of the transition from ductile to brittle behaviour. The sudden fall in absorbed energy was accompanied by

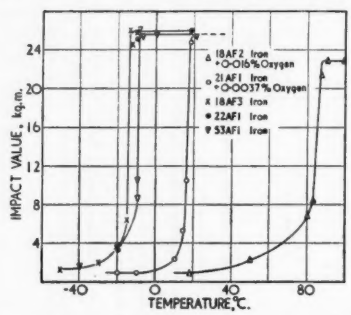

Fig. 3—Impact values, at various temperatures, of five irons normalized at 950° C.

Fig. 4—Microstructure of iron 18*AF2* showing iron oxide × 500

Fig. 5—Microstructure of iron 18*AF3* × 150

Fig. 6—Microstructure of 5% Mn alloy, showing α_2 structure. Normalized at 950°C. × 250

(a) 0·01% C

(b) 0·03% C

(c) 0·05% C

Fig. 7—Microstructures of normalized carbon alloys × 150

(a) 0·05% C, 0·5% Mn (b) 0·05% C, 1% Mn (c) 0·05% C, 2% Mn × 150

Fig. 8—Microstructures of normalized carbon–manganese alloys

Fig. 9—Microstructure of normalized 0·03% carbon – 2% manganese alloy × 150

a cleavage fracture starting at the root of the notch and extending over most of the cross-sectional area of the test piece. Just below the transition temperature, some plastic deformation occurred around the sides of the test piece and at the back face opposite the notch, where the restraint imposed by the form of the test piece was less severe. The amount of this deformation, as indicated by the tailing-off of the curves at the lower end, decreased as the temperature fell, until the whole fracture was brittle and little or no deformation was perceptible.

The transition temperatures of irons 18*AF*3 and 22*AF*1 were − 14° to − 15° C., and that of iron 53*AF*1 was − 9° to − 10° C., whereas irons 21*AF*1, and 18*AF*2, with oxygen contents of 0·0037% and 0·016% respectively, had higher transition temperatures of + 16° and + 84° C. As in the tensile tests, the brittle fractures of the low-oxygen irons were entirely of the cleavage type, whereas those of the higher-oxygen irons contained evidence of intergranular failure.

The results of the impact tests on iron 21*AF*1 in the two coarse-grained conditions, shown in Table IV, are not so regular as those for the finer-grained normalized material. This apparent inconsistency when the grains are large, is attributed to two factors, one of which arises from the tendency to intergranular failure. The occurrence of deformation or fracture in the transition region presumably depends on the orientation of a large grain, which may occupy the whole width of the notch. Whether a grain boundary is favourably placed with respect to the notch would also appear to affect the likelihood of the development of an intergranular fracture. The notch in that test piece which gave a high impact value without fracture at 0° C. happened to be in a grain which occupied almost the whole cross-section of the test piece in this region. Many more test pieces of this material were broken in the brittle region in impact than in tension, and this confirms the conclusion inferred from tensile test results, that there is more evidence of intergranular weakness when the grain

Table IV

CHARPY IMPACT VALUES OF IRON 21*AF*1 IN TWO COARSE-GRAINED CONDITIONS

Temperature of Test, ° C.	Impact value, kg.m.	
	0·55 grains/mm.	0·1–0·3 grains/mm.
−73	0·65	1·0
−30		1·4
−10		6·3
0	1·65	26·5
20	3·47	
22		2·4
23·5		20·9
27	21·55	
30	3·55	
40		20·8
50	3·0	19·6
	3·1	23·8
	9·4	21·8
		22·9
60	22·2	
70	20·9	
100	20·8	

Table V

CHEMICAL ANALYSES OF THREE IRONS MADE IN THE 6-LB. FURNACE

Element, %	3*AF*1	5*AF*3/1	8*AF*3
Carbon	0·009	0·004	0·0039
Silicon	0·005	0·003	n.d.
Manganese	<0·005	0·007	n.d.
Sulphur	0·0016	0·0037	0·0053
Phosphorus	<0·003	<0·001	n.d.
Nickel	0·002	n.d.	n.d.
Chromium	0·001	n.d.	n.d.
Copper	0·004	n.d.	n.d.
Aluminium	n.d.	0·001	n.d.
Oxygen	0·015	0·0009	$0·0007_1$
Nitrogen	0·0009	0·001	$0·001_8$
Hydrogen	Trace	Trace	Trace

n.d. = not determined

size is increased by straining and heating below the transformation temperature. A strong indication is also obtained from an examination of the brittle fractures of this iron, that the proportion of a fracture which broke in an intergranular manner decreased, giving rise to more cleavage, as the temperature of test decreased. Some variation in this respect had to be allowed, because only a few grains were involved in each fracture.

The effect of grain size on intergranular brittleness is consistent with the idea that this weakness is caused by a concentration of one or more impurities at the grain boundaries, regardless of whether such concentration is sufficient to result in the formation of a second constituent. The grain boundaries of various irons, including those prone to intergranular brittleness, have been examined (using both hand and electrolytic polishing) under optical and electron microscopes, and no definite evidence of a second phase has yet been obtained. It is possible, however, that the increased tendency to intergranular brittleness obtained by coarsening the grains was an effect of the treatment applied to obtain the coarse grains, and was not directly associated with the size of the grains.

Other observations confirm the influence of oxygen in promoting intergranular brittleness. For example, an iron was found to crack along grain boundaries during cold rolling, and one alloy behaved similarly when stamped (in the cold) after hot rolling; the oxygen contents were found to be high, 0·007% for the iron and 0·01% for the alloy. Oxygen contents tend to be high on the odd occasions when a small leak develops in the equipment. The limit of oxygen content below which intergranular brittleness was not detected in melts made in the 25-lb. furnace was about 0·002–0·003%.

Intergranular brittleness was much more evident in irons made in the 6-lb. furnace, and appeared at lower oxygen contents than in irons made in the 25-lb. furnace. The extent to which it occurred was demonstrated by the results of mechanical tests (Table VI) on three irons (3*AF*1, 5*AF*3/1, and 8*AF*3), the chemical analyses of which are given in Table V. These irons were made with a hydrogen pressure of 16 cm. of Hg. (*see* p. 157), and the time of treatment ranged from 4 to 24 hr.; the resultant oxygen contents decreased from 0·015% to 0·0007%. The two irons 3*AF*1 and 5*AF*3/1, unlike those made in the 25-lb. furnace, were almost completely brittle in tension at room temperature, whereas iron 8*AF*3,

Table VI

MECHANICAL PROPERTIES OF THREE IRONS MADE IN THE 6-lb. FURNACE AND NORMALIZED

Mark	Time of Treatment in Hydrogen, hr.	Temperature of Test, °C.	Ultimate tensile Strength, tons/sq. in.	Elongation on $4\sqrt{\text{Area}}$, %	Reduction in Area, %	Izod Impact Value, ft.-lb.
3*AF*1	4	Room	10·2	3	*	1½
		100				1½
		200	10·7	<9	8	9½
5*AF*3/1	12	Room	9·8	5	4	2½
		100	11·0	14	12	
		200	14·3	42	87	5½
		300				25½
8*AF*3	24	Room	9·8	30	13	3
		100	11·2	30	>90	4
		200				38 (unbroken)

* Broke in shoulder

with the lowest oxygen content, had considerable ductility. The fractures of the tensile test pieces changed from entirely intercrystalline in iron 3*AF*1 to intercrystalline with a little cleavage in the irons treated for 12 and 24 hr. in hydrogen. The three irons were brittle in impact at room temperature, the fractures being almost entirely intercrystalline. The materials became increasingly ductile as the temperature of test was raised. In tension, iron 3*AF*1 was still very largely brittle at 200° C., and irons 5*AF*3/1 and 8*AF*3 were completely ductile at 200° and 100° C., respectively. In impact, iron 3*AF*1 was only slightly ductile at 200° C., and iron 5*AF*3/1 still showed some signs of brittleness at 300° C., whereas iron 8*AF*3 was completely tough at 200° C. There was thus a distinctly decreasing tendency to intergranular brittleness, the transition temperatures being lower, as the time of treatment in hydrogen increased or as the oxygen content decreased. It is interesting that the sulphur content of these irons increased in the order of decreasing intercrystalline weakness.

The addition of as little as 0·75% of manganese to iron 3*AF*1 (oxygen content 0·015%) had a substantial effect in decreasing the amount of intergranular brittleness. The mechanical properties of this iron in the normalized condition are given in Table VII. When tensile and impact tests were made on the iron in the brittle condition, failure occurred partly by cleavage and partly along the grain boundaries. The manganese addition rendered the iron ductile at a lower temperature, and at any given temperature the tensile strength was increased because of some refinement of the grains.

Table VII

MECHANICAL PROPERTIES IN THE NORMALIZED CONDITION OF IRON 3*AF*2, CONTAINING 0·075% OF MANGANESE

Temperature of Test, °C.	Ultimate Tensile Strength, tons/sq. in.	Elongation on $4\sqrt{\text{Area}}$, %	Reduction in Area, %	Izod Impact Value, ft.-lb.
100				47 (unbroken)
50				8
Room	14·3	55	>90	7½
− 5	16·7	61	>90	
−50	18·5	10	9	

Iron of very high purity (Mark I iron), as produced by Adcock and Bristow,[3] which was finally melted under hydrogen in the 6-lb. furnace, was prone to intergranular brittleness although some very ductile iron was also produced by these workers.

The number of irons made in the 6-lb. furnace was insufficient to determine the limit of oxygen content (corresponding to that of about 0·002–0·003% for the 25-lb. furnace) below which intergranular weakness ceases to appear. The fact that the limit should differ for the two furnaces is of some interest. The only obvious difference in procedure that could account for it is that in the 6-lb. furnace the melt is allowed to solidify in the crucible, whereas in the 25-lb. furnace the melt is poured into a heavy chill mould.

Fast[4] found that iron containing 0·015% of oxygen had a transition temperature, in impact, about 50° C. higher than that of a similar iron killed with zirconium, titanium, or aluminium; the addition of 0·53% of manganese to an iron containing 0·014% of oxygen was also found to lower the transition temperature about 40° C. compared with that of the killed irons. On the basis of impact tests at room temperature, he concluded that more than about 0·002% of carbon could combat the effect of oxygen; but from the results of impact tests on mild steel, over a range of temperatures, he found that 0·007% of oxygen raised the transition temperature. Fast associated the presence of oxygen with failure along grain boundaries, but he did not differentiate clearly between intergranular and cleavage brittleness, and mentioned that oxygen reduced the cleavage strength, the reduction being localized at the grain boundaries. The present authors prefer to treat the two types of fracture separately and to think of oxygen as reducing the intergranular strength of iron. Once fracture starts in an intergranular manner, it is reasonable to expect that it may continue partly by cleavage. The authors have no evidence that oxygen reduces the cleavage strength; this would involve investigation at very low oxygen contents, and deductions about the cleavage strength would be valid only when intergranular brittleness was entirely absent. Fast did not find that carbon had any effect on the transition temperature in impact.

Table VIII
CHEMICAL ANALYSES OF IRON–MANGANESE ALLOYS

Element, %	0·03% Mn 26*AF*1	0·2% Mn 23*AF*2	1% Mn 27*AF*1	1% Mn 29*AF*2	2% Mn 24*AF*2	2% Mn 26*AF*2	3% Mn 27*AF*2	3% Mn 29*AF*1	5% Mn 28*AF*1	5% Mn 28*AF*2
Carbon	0·0046	0·0035	0·010	0·002	0·0036	0·0037	0·0044	0·0026	0·0043	0·003
Silicon	0·002	0·007	0·003	0·007	0·003	0·002	0·003	0·009	0·005	0·003
Manganese	0·030	0·21	1·04	1·07	2·13	2·13	2·90	3·01	4·88	4·98
Sulphur	0·0041	0·0098	0·0042	0·0028	0·0094	0·002	0·0048	0·0046	0·0056	0·005
Phosphorus	<0·001	<0·001	n.d.	n.d.	<0·001	<0·001	n.d.	n.d.	n.d.	<0·001
Nickel	0·006	0·006	0·006	0·005	0·008	0·006	0·005	0·006	0·006	0·006
Chromium	0·001	0·002	0·001	0·001	0·001	0·002	0·001	0·001	0·002	0·001
Copper	0·006	0·007	0·004	0·005	0·007	0·005	0·004	0·006	0·005	0·004
Aluminium	0·001	<0·001	0·008	0·001	<0·001	0·0035	0·0015	0·001	0·001	0·001
Oxygen	0·0026	0·0016	0·0020	0·0040	0·0023	0·0008	0·0021	0·0008	0·0007	0·0020
Nitrogen	0·0014	0·0020	0·0011	0·0017	0·0052	0·0011	0·0014	0·0019	0·0017	0·0025
Hydrogen	←				<0·000005					→

n.d. = not determined

PROPERTIES OF IRON–MANGANESE ALLOYS

The chemical analyses of a series of alloys containing up to 5% of manganese are given in Table VIII; the alloys containing 1, 2, 3, and 5% of manganese are duplicated. The 1% Mn alloy 27*AF*1 inadvertently contained 0·01% of carbon, and consequently had a small amount of pearlite in its microstructure. The grain size, after normalizing for a short time at 950° C., decreased with increasing manganese content, as shown in Table IX. The two 5% Mn alloys consisted of α_2 structure (shown in Fig. 6), which results from a diffusion-less transformation of γ to α iron on cooling from the austenitic condition. There is some evidence that this structure was present also in the 3% Mn alloys, and it is possible that it was not entirely absent from any of the alloys containing 1% or more of manganese.

The α_2 structure is known to be a distorted body-centred cubic structure, and attempts were made to minimize the lattice distortion by tempering the alloys, followed by air-cooling. The results of hardness determinations after various tempering treatments are given in Fig. 10. Complete structural equilibrium may not be obtained by tempering, but the large reduction in hardness indicates that considerable removal of the stress associated with the distorted α_2 structure has been effected. Of the treatments tried, 4 hr. at 600° C. appeared to be the most promising. Tensile and impact properties were determined after normalizing at 950° C. and after tempering at 600° C.

The results of the tensile tests at room temperature, at −73°, and at −196° C., are given in Figs. 11 and 12. The tensile properties of the series of alloys at − 196° C. are given more fully in Table XII (p. 168).

Table IX
GRAIN SIZES OF NORMALIZED IRON–MANGANESE ALLOYS

Mark	Manganese, %	Grains/mm.
26*AF*1	0·03	14·3
23*AF*2	0·21	11·3
27*AF*1	1·04	38·4*
29*AF*2	1·07	12·1
24*AF*2	2·13	17·8
26*AF*2	2·13	32·0
27*AF*2	2·90	50·7
29*AF*1	3·01	56·0
28*AF*1	4·88	Difficult to measure (α_2 structure), but somewhat finer than 3% Mn alloys
28*AF*2	4·98	

* Contained 0·01% carbon, and had pearlite in its microstructure

The effect of increasing the manganese content was a general raising of the yield (or proof) stress and tensile strength and a lowering of elongation and of reduction in area at room temperature and at −73° C. There was a general increase in ductility at − 196° C., owing to the effect of manganese in lowering the transition temperature. The yield stress and tensile strength increased approximately linearly up to

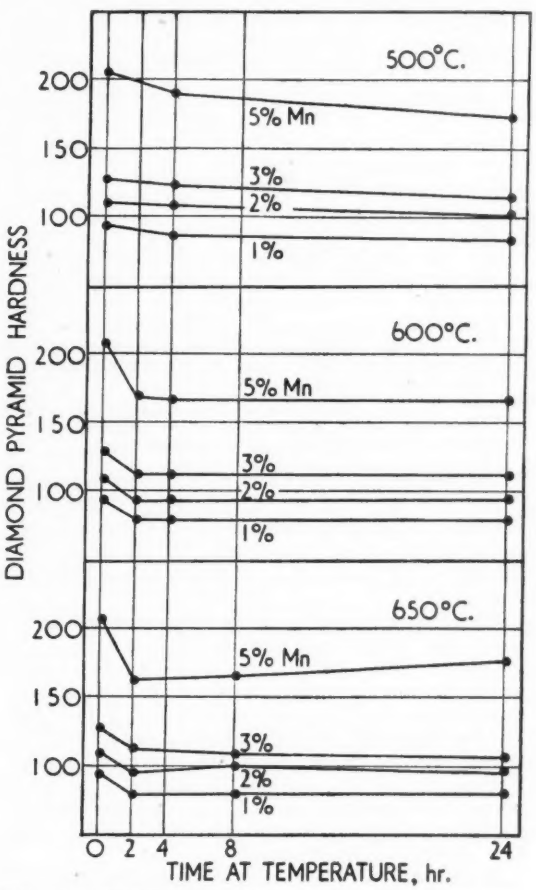

Fig. 10—Hardnesses of iron–manganese alloys tempered at 500°, 600°, and 650° C.

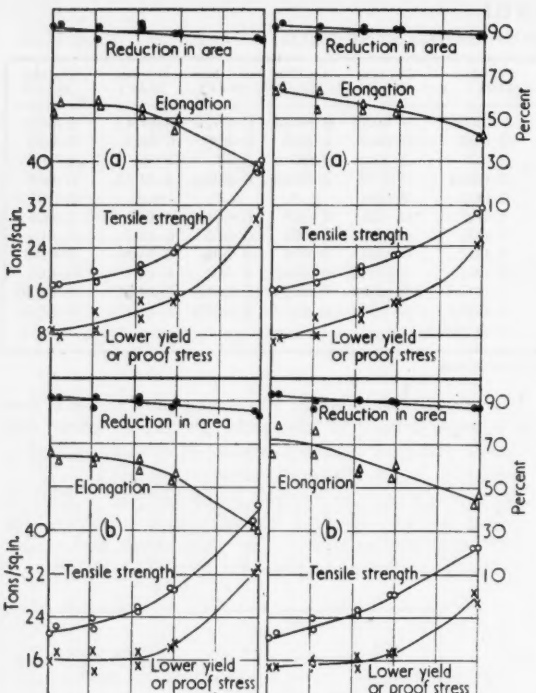

Fig. 11 *Fig. 12*

Fig. 11—Tensile properties of iron–manganese alloys normalized at 950° C. : (*a*) At room temperature ; (*b*) at −73° C. ; (*c*) at −196° C.

Fig. 12—Tensile properties of iron–manganese alloys after tempering at 600° C. : (*a*) At room temperature ; (*b*) at − 73° C. ; (*c*) at − 196° C.

2% of manganese, after which they rose more rapidly, probably because of the α_2 structure. Tempering effected a reduction of yield stress and tensile strength at the higher manganese levels, and an increase in ductility of all the alloys particularly at low temperatures.

The effect of lowering the temperature was to increase the yield stress and tensile strength of all the alloys. At −196° C. all test pieces broke with a brittle fracture, including those which had retained considerable ductility and necked before breaking. The ductility of the alloys increased down to − 73° C. Radial cracks appeared in the fractures ('star' fractures) of the 3% and 5% Mn alloys tested in the normalized condition at − 73° C., but this feature, which is thought to be associated with the α_2 structure, disappeared on tempering.

The rate of work-hardening deduced from the true-stress/strain curves is shown in Fig. 13, for the alloys in the normalized and in the tempered conditions at room temperature and at − 73° C. The rate of work-hardening rises linearly with increasing manganese content, and it is also higher at − 73° C. than at room temperature. True-stress/strain curves were not taken at − 196° C.

Two alloys—1% Mn (29*AF*2) and 2% Mn (24*AF*2) —behaved in an anomalous manner at − 196° C., being substantially more brittle than was expected ; this is reflected in their rather low brittle strengths. Whereas the fractures of the other alloys at − 196° C. were entirely of the cleavage type, in these two alloys the fractures were partly intergranular (*see* p. 160). These results are thus in agreement with those for iron, in which low brittle strengths are also obtained in the cases where failure is partly along grain boundaries. These two alloys are dealt with further in the discussion of the impact test results, but are necessarily omitted from the following consideration of the effect of manganese on cleavage strength. The term 'cleavage strength' is here used to denote the strength in the brittle condition, when failure occurs by cleavage only. The term 'brittle strength' is used, in a more general sense, to include cases where failure is partly intergranular ; brittle strength is considered to be a reflection of the intergranular strength rather than the cleavage strength, when the failure is partly along grain boundaries.

When the behaviour of these alloys is considered in terms of the yield stress and cleavage strength, the relative values of these two determining whether an alloy is ductile or brittle, then the fact that manganese lowers the transition temperature range and raises the yield stress suggests that it should also raise the cleavage strength. This is confirmed by experimental results, the yield stresses of the higher manganese alloys at − 196° C. being higher than the highest cleavage strength obtained for iron in the completely brittle condition. Moreover, if possible differences in the rate at which the yield stress approaches the cleavage strength are ignored, the effect of manganese must be explained on the basis of a larger raising of the cleavage strength than of the yield stress. The determination of the cleavage strengths of all the manganese alloys in the completely brittle condition becomes experimentally difficult, because temperatures below that of liquid nitrogen are involved.

The deformation occurring during a test at −196° C. had a large effect on the cleavage strength. The fracture stress at this temperature rose rapidly as the elongation and reduction in area figures increased, *e.g.*, on tempering.

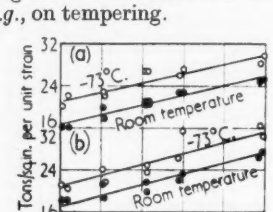

Fig. 13—Rate of strain-hardening of iron–manganese alloys : (*a*) Normalized at 950° C. ; (*b*) tempered at 600° C.

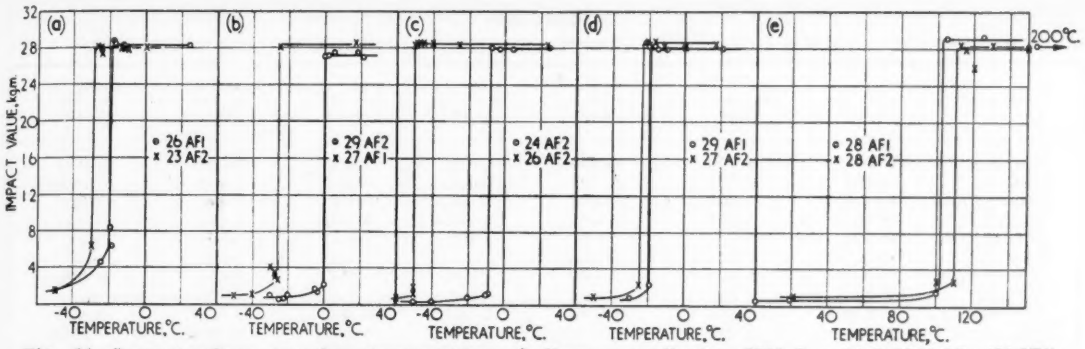

Fig. 14—Impact values at various temperatures of alloys normalized at 950° C. : (*a*) 0·03% Mn (26*AF*1) and 0·2% Mn (23*AF*2) ; (*b*) 1% Mn ; (*c*) 2% Mn ; (*d*) 3% Mn ; (*e*) 5% Mn.

The transition from ductile to completely brittle behaviour in tension occurred over a range of temperature, in contrast to the transition in impact, because the fractures at — 196° C. were of the cleavage type for all the alloys (with a trace of intergranular fracture in the two alloys 29*AF*2 and 24*AF*2), although necking occurred in a number of cases, and reductions in area up to 60% were recorded.

The results of impact tests on the normalized alloys are plotted in Fig. 14, and the transition temperatures of both the normalized and tempered alloys are given in Table X. (The impact-value/temperature curves of the tempered alloys are not reproduced, because they are similar in form to those of the normalized alloys.) A feature of the curves is the very sudden change from completely ductile to almost completely brittle fracture in alloys with 1% or more of manganese, there being very little plastic deformation at the temperature at which cleavage fracture first occurs. It will be recalled that in iron, the change from tough to brittle behaviour, whilst also occurring over a very small temperature range, was accompanied by some plastic deformation round the edges of the test piece, until lower test temperatures were used.

Alloys 29*AF*2 (1% Mn) and 24*AF*2 (2% Mn), which gave low brittle strengths in the tensile tests at — 196° C., also have higher transition temperatures in impact than were expected. In the normalized condition, the α_2 structure resulted in very high transition temperatures for the 5% Mn alloys and possibly had a small similar effect in the 3% Mn alloys. Tempering of the α_2 structure resulted in a large drop in the transition temperatures of the 5% Mn alloys, and there was a small drop in the 3% Mn alloys. With the exception of the two alloys of low brittle strengths, the effect of increasing manganese content was a general decrease in transition temperature. The high transition temperatures in impact of the 5% Mn alloys (having an α_2 structure in the normalized condition) can be explained by the presence in the distorted lattice of triaxial stresses, which would lower the additional stress necessary to cause cleavage ; however, it would be necessary to explain why the transition temperature is not also higher in simple tension.

Table X

TRANSITION TEMPERATURES IN IMPACT OF IRON–MANGANESE ALLOYS

Mark	Manganese	Transition Temperature, ° C.	
		Normalized at 950° C.	Normalized, Tempered at 600° C. for 4 hr., Air-cooled
26*AF*1	0·03	−19	−36
23*AF*2	0·21	−28	−34
27*AF*1	1·04	−26	−11
29*AF*2	1·07	0	−26
24*AF*2	2·13	−7	+19
26*AF*2	2·13	−50	−28
27*AF*2	2·90	−24	−51
29*AF*1	3·01	−19	−27
28*AF*1	4·88	+102	−41
28*AF*2	4·98	+111	−70

As in the tensile tests at — 196° C., the brittle fractures of the two alloys 29*AF*2 (1% Mn) and 24*AF*2 (2% Mn) in impact were partly intercrystalline, whereas the brittle fractures of the other alloys were entirely cleavage. This accounts for the transition temperatures of alloys 29*AF*2 and 24*AF*2 in impact being higher than those expected from the general trend of the results for the other alloys. In iron, raising the oxygen content above 0·002–0·003% resulted in failure in the brittle condition being partly along grain boundaries. The oxygen content of alloy 29*AF*2 (1% Mn) was a little high, at 0·004%, whereas that of alloy 24*AF*2 (2% Mn) was 0·0023%. Alloys 26*AF*1 (0·03% Mn) and 27*AF*1 (1% Mn) had oxygen contents of 0·0026% and 0·002% respectively, but neither alloy showed signs of intergranular brittleness. Intercrystalline weakness in alloys 29*AF*2 and 24*AF*2 was therefore generally in agreement with their oxygen contents, when compared with the results for iron, but this weakness appeared in alloy 24*AF*2 at an oxygen level slightly lower than was expected ; this may have been caused by traces of other impurities, *e.g.*, the nitrogen content of this alloy was high, at 0·005%. Quite apart from the low brittle strengths of these two alloys, the discrepancies between the pairs of 1% and 2% Mn alloys may have been accentuated by differences in amounts of impurities and also in grain size. It may be significant that the alloy with the lower transition temperature in each pair had the smaller

Table XI

CHEMICAL ANALYSES OF IRON–CARBON AND IRON–CARBON–MANGANESE ALLOYS

Element, %	0·01% C 31*AF*2	0·03% C 31*AF*1	0·05% C 30*AF*3	0·05% C, 0·5% Mn 51*AF*2	0·05% C, 1% Mn 51*AF*1	0·05% C, 2% Mn 32*AF*2	0·03% C, 2% Mn 32*AF*1
Carbon	0·0096	0·028	0·044	0·051	0·053	0·046	0·032
Silicon	0·002	0·002	0·003	0·002	0·002	0·005	0·005
Manganese	0·004	0·004	0·003	0·46	0·97	2·04	2·00
Sulphur	0·0056	0·006	0·004	0·0056	0·0051	0·007	0·007
Phosphorus	0·0007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nickel	0·006	0·005	0·005	n.d.	n.d.	n.d.	n.d.
Chromium	0·001	0·002	0·002	n.d.	n.d.	0·001	0·001
Copper	0·006	0·006	0·006	n.d.	n.d.	n.d.	n.d.
Aluminium	0·004	0·004	0·004	0·003	0·003	0·003	0·003
Oxygen	$0·001_1$	$0·001_0$	$0·0006_6$	$0·001_3$	$0·001_5$	$0·0008_9$	$0·0004_5$
Nitrogen	$0·001_2$	$0·001_2$	$0·001_4$	$0·001_2$	0·001	$0·002_0$	$0·001_5$
Hydrogen	←			<0·000005			→

n.d. = not determined

grain size and the higher aluminium content. From an examination of the Fe–C–Mn alloys, it seems that the fine grain size of the 1% Mn alloy, 27*AF*1, was due partly to its carbon content of 0·01%. It is uncertain to what extent grain size as such affects the transition temperature.

PROPERTIES OF IRON–CARBON AND IRON–CARBON–MANGANESE ALLOYS

In view of the observed effects of the manganese/carbon ratio on the transition temperatures in impact in mild steel,[5] three alloys containing approximately 0·01, 0·03, and 0·05% of carbon, three alloys with 0·05% of carbon and 0·5, 1, and 2% of manganese, and one alloy with 0·03% of carbon and 2% of manganese, were tested in tension and impact after normalizing at 950° C. The chemical analyses of these alloys are given in Table XI. The alloys contained a small amount of aluminium, owing to reduction of the alumina of the melting crucible by carbon.

The microstructures of the alloys are shown in Figs. 7–9; no carbide can be seen in the 0·01% C alloy, grain-boundary carbide and pearlite are present in the 0·03% C alloy, and there is an appreciable amount of pearlite in the 0·05% C alloy (Figs. 7*a–c*, respectively). The addition of carbon resulted in a progressive refinement of the grains. A further refinement of both the ferrite and pearlite occurred on adding manganese, and the character of the pearlite became less lamellar.

Figure 15 shows the tensile test results at room temperature, at −73°, and at −196° C., for the normalized Fe–C alloys. Increasing the carbon content raised the yield stress and tensile strength at room temperature and at − 73° C., and slightly reduced ductility. At − 196° C. the alloys were completely brittle, and broke, with cleavage fractures, at strengths ranging from 45·1 to 51·7 tons/sq. in. The effect of lowering the temperature to − 73° C. was to increase the yield stress, tensile strength, and ductility of each of the Fe–C alloys.

The tensile properties of the normalized Fe–0·05% C–Mn alloys are given in Fig. 16. The addition of up to 2% of Mn increased the yield stress and tensile strength and reduced the precentage elongation at room temperature. At − 73° C. (as in the Fe–Mn alloys containing up to 2% of Mn) there was no increase in yield with increasing manganese content, but the tensile strength was raised and the percentage elongation reduced. At − 196° C. the addition of manganese caused a pronounced increase in ductility, so that none of the alloys containing manganese was completely brittle; this indicates a progressive

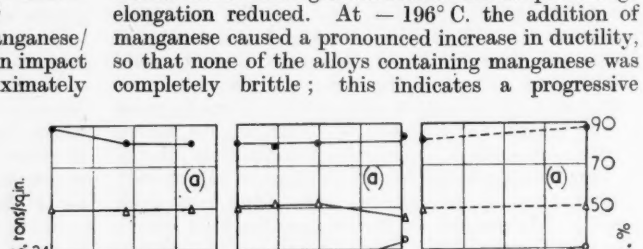

Fig. 15 *Fig. 16* *Fig. 17*

Fig. 15—Tensile properties of iron–carbon alloys normalized at 950° C.: (*a*) At room temperature; (*b*) at − 73° C.; (*c*) at − 196° C.

Fig. 16—Tensile properties of iron–0·05% carbon–manganese alloys normalized at 950° C.: (*a*) At room temperature; (*b*) at − 73° C.; (*c*) at − 196° C.

Fig. 17—Tensile properties of iron–0·03% carbon alloys, with and without manganese, normalized at 950° C.: (*a*) At room temperature; (*b*) at − 73° C.; (*c*) at − 196° C.

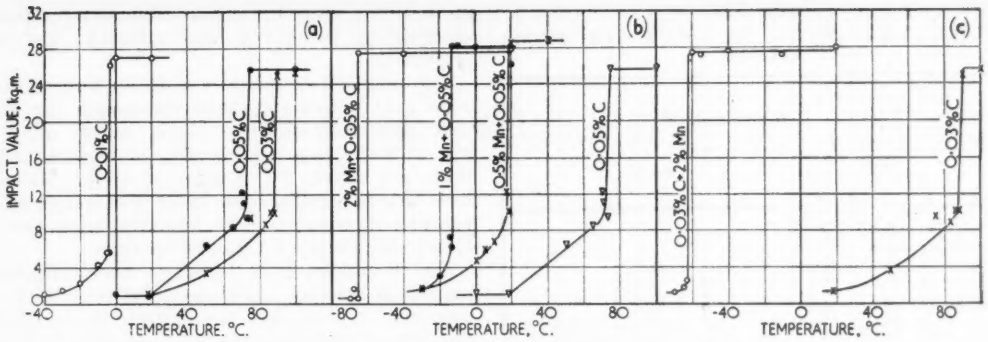

Fig. 18—Impact values at various temperatures of alloys normalized at 950° C. ; (*a*) Iron–carbon alloys ; (*b*) iron–0·05% carbon–manganese alloys ; (*c*) iron–0·03% carbon alloys with and without manganese

decrease in transition temperature. However, the fracture of the 0·05% C–2% Mn alloy, although very fine, appears to be of the cleavage type, in spite of a reduction in area of 55%.

Figure 17 shows that the effect, on the tensile properties, of adding 2% of Mn to a 0·03% C alloy is generally similar to the effect at 0·05% carbon.

Results of impact tests at various temperatures are plotted in Fig. 18. The addition of 0·01% of carbon had only a slight effect on the transition temperature in impact, but further additions raised it very considerably. Additions of up to 2% of manganese to 0·05% C alloys progressively lowered the transition temperature from + 75° C. to — 65° C. A similar effect occurred at 0·03% carbon, and it is interesting to note that at this carbon level the transition temperature was a little higher than at the 0·05% C level, both with and without the addition of 2% of manganese.

When comparing the results for the Fe–Mn alloys with those for the Fe–C–Mn alloys, it is apparent that the effect of manganese and carbon together, in raising the yield stress and lowering the transition temperature, is greater than when manganese is present alone.

The effect of carbon in raising the transition temperature in impact might be explained in terms of an increase in yield stress without much effect on the cleavage strength. In the Fe–C–Mn alloys, increasing manganese raised the yield stress in tension at room temperature, but at — 73° C. there was no increase in yield stress with 0·05% carbon as the manganese content was raised up to 2%. With 0·03% carbon, 2% of manganese lowered the yield stress at — 73° C., but there is only one result available and it does not affect the necessity in the general argument of allowing for an increase in yield stress from room temperature to — 73° C., which is the range of temperature within which the transition from tough to brittle fracture in impact is lowered by increasing manganese. From this it can be argued that the cleavage strength is raised by manganese in the presence of carbon. In considering the transition in tension, Figs. 16*c* and 17*c* show that, at — 196° C., the yield stresses of the alloys containing manganese are slightly lower than the cleavage strengths of the manganese-free alloys at both 0·03% and 0·05% C levels, but are approximately constant with increasing manganese content. Therefore, as the transition temperature is decreased, the cleavage strength should be raised. There may be a sharper rise in the yield stress as the cleavage strength is approached than would be indicated by tests at higher temperatures, and the above argument assumes that there are no great differences in this respect as the composition is changed. This is the range in which deformation becomes increasingly difficult, and if the three planes of slip ceased to operate in turn it might be reasonable to expect a more pronounced raising of the yield stress than interpolation of the present results would suggest. To obtain a fuller picture, it would be necessary to determine the trend of the yield stress just above and within the transition region.

CONCLUSIONS

The purest irons that have been prepared in the 25-lb. furnace are very ductile at room temperature and at —73° C. when tested in simple tension, but become brittle on cooling to between — 73° and — 196° C. Fracture at — 196° C. takes place by cleavage with less than 5% elongation, at a stress of about 45 tons/sq. in. The transition temperature in the Charpy impact test with Izod **V** notch occurs at about — 15° C. These conclusions refer to material that has been chill cast, rolled, and normalized.

Iron prepared in the same way, but containing more than 0·002–0·003% of oxygen, has properties very similar to those of high-purity iron in the ductile condition ; however, when the iron is embrittled by cooling to — 196° C. the tensile strength is much lower (27–33 tons/sq. in.), and the fracture is partly intergranular and partly cleavage. The impact transition temperature rises with increasing oxygen content, and the brittle fractures are again partly intergranular.

The limit of oxygen content below which intergranular fractures are not encountered is less in irons of similar purity prepared in the 6-lb. furnace, in which the iron was allowed to solidify slowly in the crucible instead of being chill cast.

Intergranular brittleness in an oxygen containing iron can be made more evident by coarsening the grains by straining and heating below the transformation temperature. The addition of up to 5% of

Table XII

TENSILE PROPERTIES AT −196° C. OF Fe–Mn ALLOYS

Mark	Mn, %	Lower Yield or 5% Proof Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elong. on $4\sqrt{A}$, %	Red. in Area, %	Fracture Stress, tons/sq. in.	Fracture
Normalized at 950° C.							
26AF1	0·03	37·5*	43·5	4	2	44·0	Cleavage
23AF2	0·21	38·9*	41·3	2·5	3	42·2	,,
27AF1	1·04	41·5	45·6	14	13	52·6	,,
29AF2	1·07	†	36·8	1	1	37·3	,, ‡
24AF2	2·13	37·6*	38·4	1	2	39·4	,, ‡
26AF2	2·13	40·8	47·2	18	17	57·1	Cleavage
27AF2	2·90	41·8	47·5	29	27	77·4	Cleavage and necking
29AF1	3·01	42·8	47·2	39	46	72·7	,, ,,
28AF1	4·88	54·3*	58·5	8	7	63·3	Cleavage
28AF2	4·98	56·2*	61·7	19	24	77·7	Cleavage and necking
Normalized, tempered for 4 hr. at 600° C., A.C.							
26AF1	0·03	34·2*	44·1	10	10	48·8	Cleavage
23AF2	0·21	36·6*	44·9	12	10	49·4	,,
27AF1	1·04	43·2	47·1	49	43	73·0	Cleavage and necking
29AF2	1·07	†	36·5	26	20	46·2	Cleavage‡
24AF2	2·13	36·5*	39·0	4	5	40·6	,, ‡
26AF2	2·13	~41	46·1	§	~20	~57·2	Cleavage
27AF2	2·90	42·3	46·4	39	32	74·4	Cleavage and necking
29AF1	3·01	42·2	46·3	36	42	71·6	,, ,,
28AF1	4·88	48·9	53·5	35	47	86·9	,, ,,
28AF2	4·98	48·6	53·8	40	60	103·0	,, ,,

* 0·5% proof stress, no yield
† No yield or proof stress
‡ Some intergranular
§ Broke at shoulder

manganese to pure iron increases the yield stress and tensile strength; at −196° C. there is also an increase in ductility. No intergranular fractures were observed except in two anomalous alloys that had inferior properties. The tensile test results indicate that manganese increases the cleavage strength of iron more than it increases its yield stress.

Manganese decreases the impact transition temperature of iron, provided that the distorted α_2 structure is not present. This structure appears in the normalized alloys containing 3 and 5% of manganese, and raises the impact transition temperature, but this effect can be removed by tempering.

The addition of 0·01% of carbon to high-purity iron has very little effect on the tensile and impact properties of normalized material. Larger additions, up to 0·05%, raise the impact transition temperature appreciably, without a large effect on the tensile properties.

The addition of manganese to an iron containing 0·05% of carbon progressively lowers the impact transition temperature, which, in an alloy with 2% of manganese and 0·05% of carbon, is lower than in a simple 2% manganese alloy. Manganese and carbon together also lower the transition temperature in tension. The fractures, when not completely ductile, are of the cleavage type.

The transition from tough to brittle fracture in impact is usually very sharp in iron and iron–manganese alloys that fail entirely by cleavage in the brittle condition, but it tends to be less sharp when fracture is partly along grain boundaries. The addition of carbon to iron also spreads out the lower end of the transition, but the sharpness is progressively restored by additions of manganese. The transition from tough to brittle fracture in tension covers a range of temperature in iron–manganese and iron–carbon–manganese alloys, and it seems likely that this applies also to iron and iron–carbon alloys.

Acknowledgments

The work described in this paper was carried out in the Metallurgy Division of the National Physical Laboratory, under the direction of Dr. N. P. Allen, on behalf of the British Iron and Steel Research Association, and is published by permission of the Director of the Laboratory and with the approval of the Association.

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Discussion on Electric Drives

(*Continued from p. 174*)

Does the author know of any quick and reliable practical method of reproducing an established strength of electrolyte for slip regulators? If a slip regulator has to be drained, it is very desirable to re-establish immediately the conditions which have been arrived at by trial and error over probably an extended period.

Finally, I think more consideration should be given to the aesthetics of machine construction.

Mr. **Peck** wrote in reply: The tendency to offer higher-speed motor generator sets is surely governed by the purchaser rather than by the manufacturer. Most manufacturers would sooner offer lower-speed sets, but few purchasers are willing to pay the extra price involved for the sake of quietness.

A good deal of work has been done on large A.C. machines in regard to reducing windage noise; but the D.C. machine is a very different proposition, and as reduction in speed (the only effective way to reduce noise) inevitably increases the size, it also increases the cost.

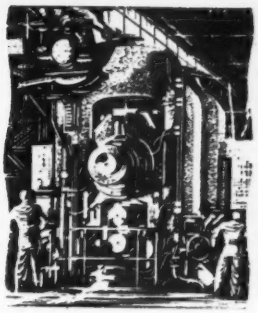
It is not usual to have more than 1000 V. on a single-armature mill motor, and if the power demands more than two generators to supply it the voltage per generator (with series connections) would be rather low for a well-balanced design. Each case needs to be considered on its merits.

Mr. Gaskell's remarks on pulpit arrangements are helpful, and I agree that there is something to be said for a 'mock-up'.

The most accurate method of establishing the strength of an electrolyte is by titration against a standard acid; from this the weight of chemical per gallon of water can be estimated, and used when refilling.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FOURTEENTH MEETING

The Fourteenth Meeting of the Iron and Steel Engineers Group of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Thursday, 5th April, 1951. Mr. C. H. T. Williams (The Park Gate Iron and Steel Co., Ltd.), Chairman of the Group, occupied the Chair.

The Morning Session was devoted to the presentation and discussion of the paper: "Electric Drives for Reversing Hot Mills," by P. E. Peck (British Thomson-Houston Co., Ltd.).

The Afternoon Session was devoted to the presentation and discussion of the paper: "Hot Bloom and Slab Shears," by J. A. Kilby (Colvilles, Ltd.).

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

Discussion on the Paper—

ELECTRIC DRIVES FOR REVERSING HOT MILLS*

Mr. **P. E. Peck** (British Thomson-Houston Co., Ltd., Rugby) introduced the paper.

Mr. **P. F. Grove** (John Miles and Partners (London) Ltd.): This paper comes at the time of the starting up in South Wales of the largest British rolling-mill drive yet built. Twin-drive motors are incorporated and the drive is, I believe, the second largest size in the world, having a peak torque of 3,600,000 ft.-lb. (490 metre-tons), which is 27,600 h.p. at 40 r.p.m. Many of the older reversing-mill motors have, however, given first-class service since before the first World War. There is also a group of 7000- to 25,000-peak h.p. motors built from 1919–1922, mostly double-armature machines and many of them running in their original condition.

The pioneers of rolling-mill drives, Captain C. A. Ablett, Mr. L. Rothera, and Mr. G. M. Brown, did much to establish the electric drive for reversing mills. In 1909 Ablett† emphasized the lower running costs, the lower maintenance, and the greater convenience of operation of electric drives. It is difficult to justify the high running cost of the steam drive still used for the slabbing mill of one of the most modern steelworks in this country, even though the mill and auxiliaries have recently been reconstructed.

The peak torque occurs usually during the first few passes near the base speed, and cannot occur again at higher speeds for longer passes, but the author's paper gives the impression that the peak torque is at high speed. The author's statement under "Power Requirements" (p. 309) that "the power required for forming the metal can be supplied by a large-diameter roll revolving at a relatively low speed or by a smaller diameter roll revolving at higher speed" needs some explanation in relation to rolling practice. There is a general ratio between roll diameter and roll length, but the proportions are fixed mainly by the materials to be rolled and not, as might be assumed from the paper, by any electrical power characteristic.

Although the author says that "the metal is usually entered at base speed," it is sometimes entered at a lower speed.

Some information on the present position in regard to insulation and possible future changes would be useful in conjunction with this paper, since insulation is of great importance to a heavy reversing motor. It may be accepted that Class *B* insulation is universal, but this fact might be stated and some emphasis laid on the need for very robust armature insulation to stand the continual reversals that take place (about 2,000,000 a year.) Some motors have run for 30–40 years without trouble, but I have seen a case where the mica insulation was pulverized almost to dust, although this had no effect until the outer cover gave way. Poor ventilation resulting from blackout restrictions and from protective measures against bomb damage during the last war, probably had an effect on insulation.

I see no mention of compensating windings, which are an essential part of machines operating over these wide ranges of power and speed. Some indication of voltages

* *Journal of The Iron and Steel Institute*, 1951, vol. 167, March, pp. 309–323.

† C. A. Ablett, *Journal of The Iron and Steel Institute*, 1909, No. II, pp. 15–21.

would be useful, even though they may not vary much between different designs of motor.

Perhaps the author would explain the methods for building up double-armature motor rotors. At one time the two armatures were built on a single shaft, but it is now normal practice to mount each armature on a stub shaft with a large diameter half coupling and to bolt the two together. Welding is used to a great extent, but I think some guidance as to how this has supplanted cast steel for armature rotors would be useful.

The first twin drive in this country was tried out about 1921 on the existing mills at the Skinningrove Iron Co. Two mills were in line and, by taking out pinions and coupling through the rolls, it was possible to use two separate motors. There have been some smaller twin drives in this country, but the main advance has been in the U.S.A. and Canada. The Homestead 160-in. plate mill is designed to roll down to $\frac{1}{4}$-in. thick material without curling, which seems a remarkable achievement.

I think there will be some need for standardization between makers of reversing-mill motors in this country and in America, if between us we are to satisfy the markets of the world. The author gives some useful information about the relationship of flywheel size and driving-motor power, but the optimum speed of the flywheel affects the design. The Americans employ lower speeds for their sets with fewer but larger generators, and claim to run under easier conditions with a much heavier flywheel, whereas we employ higher-speed sets with more generators and smaller flywheels. Some discussion might be useful on the balance between the windage losses of flywheels with high peripheral speeds of 28,000 ft./min. and on the noise, brush wear, and more difficult commutation of the higher-speed generators.

There have been claims for the use of rectifiers on reversing mills, but it is difficult to understand how they could ever be a practical success with continual high-speed reversals; the use of flywheel energy to protect the supply system is still rather necessary.

I agree with the author that much thought should be given to ventilating layout. To draw large quantities of air into the motor through filters from outside, frequently causes them to be neglected, with resulting bad conditions. Foot control would be more tiring than hand-lever control, but it frees the operator for manipulating duties. The author shows the amplidyne method of control, but there are other quick-response methods, and I should like to ask whether electronics offer any better alternative for the future than the rotating exciters, which require a certain amount of maintenance.

Mr. **P. E. Peck**: The curve of response shown in my paper (Fig. 17) is actually taken from one of the mills put down in the 1919–21 period, and which has been recently modernized by the addition of the control scheme, which I have explained. I believe that the owners expect to get another 30 years' life out of it. This particular type of mill made use of a feature to which Mr. Grove referred, the arrangement of a double-armature motor in which each armature is arranged on a stub shaft at the outer end, and the two inner ends are bolted together by flanges of large diameter as part of a spider; this results in a very rigid construction, and has recently been adopted in the U.S.A. as a modern development.

In regard to peak torque, what is actually stated is that the size of the drive depends on the highest torque required and on the highest speed at which that torque is required. These two factors together give the base-speed rating of the machine. Higher speeds than that are of course required, but only at reduced torques, and are obtained by field weakening of the mill motor.

My reference to the effect of reduced roll diameter was made with the proviso that it was compatible with the necessary strength and rolling requirements of the mill. There are physical limitations, but the smallest possible diameter of roll, which can give the required mechanical strength, etc., will result in the least expensive mill motor.

Generally speaking, it seems to be the practice to enter at base speed on slabbing or plate mills. On section mills considerably lower speeds are used, particularly when threading a pass into a section-shaped opening.

Others will be better able to deal with the subject of insulation than I am. Compensating windings are essential for all mill motors and form part of the electrical design.

In the organization with which I am associated, the use of cast steel on reversing-mill motors has ceased entirely, and I believe that this is the case throughout the country. Twin drives for this class of mill have been supplied down to as low as 2500 h.p. per motor, (a total of 5000 h.p.), in the U.S.A., and the maximum figure is that stated by Mr. Grove.

The subject of flywheel peripheral speeds is one on which a great deal of discussion has taken place. Even with reduced diameter, use is still made, if possible, of the maximum permissible peripheral speed. Losses are not easy to assess, but as an example of the sort of losses obtained, on a 150,000-h.p.-sec. flywheel at 750 r.p.m., the flywheel losses will be about 25–30 tons, the windage losses about 40–60 kW., and the bearing losses will be approx. 20–30 kW., making a total of 80–90 kW.

It will be a long time before rectifiers are generally accepted for reversing-mill drives, if they ever are. At the moment, we can say that for these drives we do not contemplate using electronics in place of quick-response regulators. If something new is introduced, it is more likely to be on the lines of magnetic amplifiers.

Mr. **H. Williams**: (Metropolitan Vickers Electric Co., Ltd.): On twin-motor drives the motors may be connected in series or in parallel. When two machines, not mechanically coupled, are connected electrically in series, there is a tendency, at starting, for one machine to run away at double voltage leaving the other machine at rest. Special features, such as a three-wire system and the attendant large-current contactors, therefore have to be introduced for starting purposes; however, since the drive is continually starting and stopping, this arrangement is not altogether ideal.

With the parallel connection, the problem of load sharing between the motors may be overcome by using cross-connected cumulative and differential series windings on the motors. This modification is simple and robust, but care has to be taken if individual motor circuit breakers are used, to ensure that, should one motor trip out, the other is not left with a strong series field in opposition to the main shunt field.

Further, on small-diameter machines, the physical size of the field magnet will not always permit heavy current series windings to be built into the machine and series exciters or load-balance exciters must be introduced, which means additional rotating machinery.

Perhaps the author would give his opinions on the choice between the series or parallel connection.

Another point which arises on twin-motor drives, or any long-core machine, is the aggravation of commutation problems. Small-diameter, long-core machines have relatively high inductance interpole windings compared with large-diameter, short-core machines. This means an increased lag between the interpole flux and the main pole flux, which has very deleterious effects on the commutation of overloads at weak-field speeds.

Has commutation yet imposed a limit on core length, or, are there any schemes in hand for varying interpole strength with load and speed, to give improved commutation on peak loads at high speed ?

Mr. **P. E. Peck**: With the two motor armatures in parallel on the busbars, and with two or more generators feeding them, the generators will probably be cross-compounded to assist load sharing. When the two motor armatures are in series, to obtain the full advantage, the generators will also be in series. If there is a slight difference in the frictional resistance of each armature, or of the rolls to which it is connected, one armature will start up and the other will remain stationary, as mentioned by Mr. Williams, unless some precautions are taken. To ensure a balance of voltage across the armatures, either arrangement in Fig. A is possible.

In arrangement (*b*), a second circuit can be connected at *X*, and the two circuits must be matched by generator voltage to restore balance. The system has the disadvantage that if one generator fails, the drive is rendered useless if there are only two generators. If there are four generators one of the other generators must also be cut out: the mill can then run at the same torque but at half speed.

With the parallel connection (*a*), it is usual to have some load-balancing arrangement between the two machines. A booster may be used in each machine field, the boosters being oppositely excited from a pilot exciter, which measures the difference of the voltages appearing across the compensating windings of the two machines. Inter-tripping between the motor breakers, so that if one opens the other opens as well, must be ensured.

In arrangement (*a*), if a generator fails rolling is possible at the same speed but at reduced torque. If a high-speed protective arrangement is used, it is not necessary to introduce line circuit-breakers in arrangement (*b*), except perhaps in the circuit that provides the balancing arrangement. Circuit-breakers are necessary with arrangment (*a*), to prevent feedback from one motor or generator armature to another in the event of a fault.

In regard to the size of cores and the question of commutation, much work has been done on the use of interpole bucking windings fed from a series exciter, energized in proportion to the load current and arranged to give a different degree of buck as the speed of the machine is increased by field weakening. Such systems are in operation on reversing hot mills and have given good commutation at both ends of the speed range.

Mr. **H. S. Carnegie** (English Electric Co., Ltd.): The author emphasizes that manœuvring should be as short as possible, but what is possible electrically, might mechanically be undesirable. With too rapid acceleration and reversing, hammering and slogger will occur if there is slackness between various parts of the drive: there has been more than one case where the user has asked for the rate of acceleration to be reduced to prevent slogger and wear.

Another point is in regard to the temperature rise and the torque conditions. In Fig. 2 of the paper the cut-out torque is three times normal, and the author refers to a 50° C. temperature rise as being normal for that machine, but he also states that the American practice is a 50° C. rise on the mill motor, and a cut-out torque of $2\frac{3}{4}$ normal. In other words, with a 50° C. temperature rise the mill motor will have $2\frac{1}{4}$ × full-load torque and $2\frac{3}{4}$ × full-load torque for working and cut-out values, whilst with the 40° C. temperature rise motor these values will be $2\frac{1}{2}$ and 3. It seems that the 40° C. rise motor would better suit the conditions of blooming and slabbing mills.

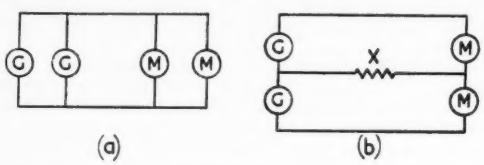


Fig. A—Circuits to ensure balance of voltage across armatures

In regard to the series *versus* parallel connections of reversing-mill generators and motors, in a mill drive with a pinion housing the series arrangement of both generators and motor or motors seems preferable because of inherent load sharing, absence of cross-connected series field windings, greater simplicity, and full torque at lower speeds.

In a twin drive the above reasons also apply provided that an equipotential midwire connection is made with a small resistance in its circuit. This midwire is mainly of use when there is no metal in the rolls and it ensures that the twin motors work together. When the metal is in the rolls the motors are, in effect, mechanically coupled, and the series arrangement then enables both motors to accommodate themselves to the metal and inherently share the load. This method was employed in the first twin drive installed in this country about 19 years ago and has worked very satisfactorily: the mill rolls were 24-in. dia. and both main motors and an edging motor were supplied from one generator with a midwire small static balancer. More modern equipments use a small control generator in the midwire connection for torque and speed control.

Advantages of the twin drive, additional to those mentioned by the author (*see* p. 315) are: a 5% reduction in the power consumption; reduced lubrication costs; lower crane capacity because, in effect, there are two smaller armatures to lift instead of one large one; and reduced cost of spares (there are no pinion spares).

A comparison between double-armature and single-armature twin drives is given in the paper, and mention is made of the American practice of reverting to single-armature twin drives. This may be partly because of their longer core lengths and smaller-diameter armatures. Double-armature twin drives for large equipments have some advantages; they have lower inertia, better commutation, inherently faster field response, and they require a lower crane capacity.

For synchronous motor-driven Ward Leonard sets used on finishing mills, I would prefer a larger synchronous motor with constant excitation, as it is simpler, and not more costly than a reduced size of synchronous motor, which relies on extra apparatus for its torque margin and power factor control. A synchronous motor with constant excitation will give a fairly constant power factor on the overall system which supplies it, even if the motor load varies considerably.

The author mentions that the size of the A.C. drive of a motor is dependent on the average output. I would suggest that it might be better to base it on the maximum output of the mill multiplied by the units consumed per ton. If the mill can give 130 tons/hr. with a consumption of 20 units/ton, then the induction motor cannot be lower than 2600 kW. This motor, of course, is not a very expensive item, and, as the author said, it may pay to increase the size of the induction motor and reduce the flywheel capacity.

I can add to the author's example of the losses of the mill motor given on page 317. On a large twin drive recently put into commission, the motor and the mill were turned with a power within the capacity of a motor-car battery. This is possible only with a forced lubrication system.

With modern control gear one can get very prompt action, current limitation, voltage regulation, regenerative control, and so on, from the use of amplifying exciter control. On the other hand, many of the equipments in this country use much simpler control, and some users, I think, would prefer simpler control and perhaps prevent some of these peaks arising, as they do, from the snatching of the operator's lever. A servo-mechanism imposed between the driver's lever and the controller has proved quite useful. The operator can snatch it over from full to full, but the servo-mechanism will give a minimum time of controller movement. It is particularly important to control the time of deceleration, since this is more detrimental to commutation than acceleration.

The Americans favour foot control, and it has been satisfactory both in the U.S.A. and in this country, but hand control may be still better and smoother. I know of one firm in America who had their installation put in with foot control, but they have reverted to hand control, using foot control to operate auxiliaries.

Mr. **P. E. Peck**: In speaking of the ratings of British and American machines, I was referring to a 50° C. rise in both cases, and the point was that the British method of rating, with $2{\cdot}5 \times F/L$ working peak and $3{\cdot}0 \times F/L$ cut-out peak, gives a more accurate picture of the machine's capabilities than the American method, with $2{\cdot}25 \times F/L$ working peak and $3{\cdot}0 \times F/L$ cut-out peak.

The 40° C. temperature rise machines mentioned by Mr. Carnegie were not considered in the paper, as 50° C. rises with 2·5 and 3·0 peaks are perfectly practicable and usual today.

In referring to the fact that the size of the induction motor is dependent on the average load I meant that its power should be fully up to the capacity of the mill.

Mr. **W. J. Pool** (The British Thomson-Houston Co., Ltd.): Motor rating is very often thought of simply in terms of horsepower, but a given horsepower can be obtained either from a high-torque low-speed machine or from a low-torque high-speed machine. The former is very superior to the latter, from the production point of view, particularly in the case of blooming mills. I will illustrate this by a simplified example (the figures will not stand detailed criticism, but are generally of the right order). In a blooming mill the metal is actually between the rolls for about one third of the total time, say for 30 sec. out of 100 sec., the remaining 70 sec. being taken up in intervals. If the motor speed were increased by 50%, the most that could be achieved would be to reduce the rolling time to 20 sec., but the 70 sec. interval time would remain untouched, so that the total time per ingot could be reduced only by about 10 sec. and the output would be increased by 10%. If, on the other hand, the torque is increased by 50%, the number of passes could, to a first approximation, be reduced to two thirds; this reduction would apply not only to the time taken between rolls but also to the time occupied by intervals, so that, to a first approximation, the output would increase by 50%. (In practice, it would not be possible to achieve as great an increase in output as indicated, but this example does show the relative effects of increasing speed and increasing torque.) It is realized, of course, that the initial cost of the low-speed high-torque motor is much greater than that of the low-torque high-speed machine

On the question of driver's controls, the control of the mill itself has to be co-ordinated with the controls of of a considerable number of auxiliaries, and if a desk is to be used I suggest that all these controls should be combined in it. To do this properly requires the collaboration not only of the designers of the mill drive and of the the auxiliary control equipment, but also of the user and probably the actual mill operator as well. The alternative scheme, which is most frequently followed, is to supply all the controllers, including the mill controller, as separate items, leaving the user to arrange them in the way most convenient to him. It would be interesting to have opinions from users on the relative merits of these two alternatives.

Also, there is the question of the optimum size and travel of the driver's control lever. It is sometimes suggested that a short finger-tip control type of lever is the ideal, and modern control systems render this at least theoretically possible, although there are practical difficulties. However, when we had a 3-ft. long old-fashioned heavy control lever replaced by a lighter one 15 in. long, the first reactions of the driver were by no means favourable. I personally think that this intermediate size is about right, but again the views of users would be of interest.

Mr. Carnegie has queried whether such elaborate control systems, including automatic load limiting, are always necessary. I am satisfied that load-limiting controls are desirable, although they may not always be economically practicable on the smaller mills.

Some reference has been made to rectifier drives; these are always possible, but in my opinion are unsuitable owing to the complications and other disadvantages involved with reversing hot mills. However, there has recently been a revival of interest in Germany. The latest idea—which has been applied to an aluminium mill—is to have a single rectifier giving unidirectional flow of current, and to reverse the main armature connections automatically, when reversal or regeneration is necessary, by means of a very heavy pneumatically operated contactor. It would be interesting to know what experience has been gained in practice on this scheme, and what the maintenance on the contactor is like.

Mr. **P. E. Peck**: Mr. Pool commented on the greater value of torque as compared with speed. I think that an unnecessarily large speed range is sometimes demanded, even when the base-speed torque is all that is required, because although theoretically it is possible to attain the same horsepower at higher speeds with reduced torque, this involves a machine which is more difficult electrically, and may, if the speed range is too wide, mean using a larger machine.

Mr. **E. Willis-Jones** (Metropolitan-Vickers Electrical Co., Ltd.): Mr. Peck states: "With a modern control scheme a reversing-mill drive can be reversed from base speed to base speed within 1½ sec. without much difficulty." It would be interesting to have some idea of the weak-field reversing time. Could the author please clarify his derivation of the Wr^2 formula, and state what is contained in the constant?

One of the primary considerations in reversing electrical drives seems to be the commutation of heavy overloads on reversals from weak-field speeds, because, with manual operation of the control lever, unless some delay is introduced, a very high regenerative peak would occur before the motor field had time to strengthen appreciably. The required delay could be achieved by delaying the generator voltage reversal until the motor field had strengthened, but this would increase the time of reversal.

Mr. **P. E. Peck**: On the mill from which the recorder chart (Fig. 17) was taken, the weak-field to weak-field time was 4½ sec. to 95% of the speed change, which was 100 to 100 r.p.m., and then another 2½ sec. levelling out. We do not regard that as the last word, because this is a modern control adapted to a very old drive, and in the original exciter sets there were considerable limitations in the degree of forcing which could be obtained.

The Wr^2 formula is based on one or two fairly simple assumptions: a constant ratio of core length to diameter, a constant core depth, a constant electrical loading, and a constant base speed.

I think that the chief reason for commutating difficulties over a wide speed range is the variation in magnetic saturation at the roots of the commutating poles, which means that the ampère-turns on the commutating pole produce a larger flux effect at weak fields than they do when the main magnetic circuit is saturated.

The regenerative peak is best limited by controlling the rate of decay of generator voltage so as to limit the current to the maximum which can be satisfactorily commutated. In the scheme described, the current is limited to about 1·5 to 1·75 times full-load current quite independently of the build-up of the motor field, and this value of current gives perfectly adequate retardation times.

Mr. **G. M. McIlwrick** (British Thomson-Houston Co., Ltd.): The question of insulation life has been raised. There have been modern improvements in insulation and in the methods of applying it (new stickers and varnishes), and with these, even at the higher speeds and torques now obtaining, there is good evidence that modern machines will probably have a very much longer insulation life than older machines, many of which are still running well after more than 30 years.

Commutation, as the author has said, is affected by many factors, including pole saturation and reactance voltage. Recently we have completed machines of which the core lengths are approximately 1½ times the diameter, compared with the normal maximum core length of 75% of the diameter. In addition, these machines have a speed range by field weakening of 4½ to 1, and the commutation right up to peak loads, is perfect.

The increase of the torque/weight ratio mentioned by the author (p. 314) is very pronounced with the modern high-speed cold-strip rolling mills, of which the one now nearing completion for the Steel Company of Wales is the only representative in this country. The tests on the machines have been most satisfactory.

Mr. **J. A. Kilby** (Colvilles, Ltd.): I understand from my colleagues Mr. L. Rothera and Mr. W. T. Hand, who were largely instrumental in carrying out the twin-motor-drive experiment at Skinningrove, that the Americans were not interested in this type of drive at the time.

Of the six or eight main drives that have been installed or are being installed in reversing mills in this country, only two are of the twin-motor type. Does this mean that the advantages which have been claimed for the twin-motor drive by previous speakers are more academic than real? As an engineer I am attracted by the twin-motor drive, because it eliminates certain mechanical elements which can cause trouble (although, with modern designs, this is now less likely to happen). In fact, the pinion housing unit, as now constructed, is so carefully designed in detail and so generously proportioned that the possibility of mishap is almost negligible.

I would be interested to know whether, apart from any operational advantages, the twin-motor drive can show any savings in capital and/or operating costs in comparison with the more orthodox drive.

Mr. **P. E. Peck**: I think the reason why more twin drives have not been installed in this country is possibly that the size of our drives, which tend to be smaller than those adopted by the large American firms, is not really great enough to warrant it. If we adopted 7000–10,000-h.p. drives there would be no question about the matter, but at present it is doubtful whether it would be worth while to use the twin drive.

Mr. **J. H. Butler** (Stanton Ironworks Co., Ltd.): Recently I was connected with a concern operating large slabbing- and plate-mill reversing drives, and I should like to offer some comments based on my experiences with this equipment. Inside the Ilgner house there is little reason for any major troubles being experienced, since the conditions should be fairly ideal. However, I would emphasize the need for clean and satisfactory ventilation, and would draw attention to the effects of aged insulation, particularly on a comparatively old installation. Most of the troubles that I have experienced inside the Ilgner house have been associated with the latter, since an accumulation of dirt in the windings can be a troublesome factor, and the effect of insulation ageing may give rise to electrical breakdown.

It is outside the Ilgner house that appreciable production time can be lost, particulary when plant has been installed for some years. I doubt, therefore, whether a main drive cyclic reversal of 1½ sec. is justified. A big percentage of the time lost on a reversing mill is associated with such auxiliaries as approach tables, breast roller drives, screwdown gear, etc., rather than with the main drive itself, and a large proportion of these troubles is usually associated with metal fatigue. The fact that all these ancillaries have to keep pace with the main mill reversal cycle surely encourages the occurrence of such fatigue problems.

Mr. Pool pointed out that the actual rolling time is a comparatively small percentage of the total time for dealing with an ingot; I think, therefore, that the designers should not introduce too many refinements, with their attendant trouble potential, in order to achieve fractional second improvement in the reversal-cycle time.

Mr. **P. E. Peck**: I am inclined to agree that the very fastest times are not always needed, but all the inquiries we receive give the impression that customers, or the mechanical engineers who draw up the specification, want the quickest reversal time possible. The modern form of control that has been described does provide a quick response, but under very controlled conditions, and results in less 'peaky' loads on the mills during reversals than do some of the older controls, which sometimes have slower reversal times but in which the load-limiting control systems are much more peaky or jerky in action. A present-day reversal time of 1½ sec. probably imposes less strain on the mill (so far as the mill motor is able to impose such strain) than some of the older drives, which may have taken up to 2 sec. for the reversal time.

Mr. **J. H. Butler**: I agree that the main drive does not suffer so much; it is rather the ancillaries which have to keep pace with it. Possibly, the same degree of care is not taken in ensuring that they cannot be abused.

Mr. **J. Higson** (Dorman Long and Co., Ltd.): The author refers to the use of rolls having minimum diameters. Apart from the limitations of 'maximum' roll diameter due to size of frames, and the lift required for the size of ingot to be rolled, roll life is a very important point in roll design. For cogging duty, where the load is carried on the roll necks, the rolls must be stiff and are therefore made as large as possible. Furthermore, the rolls must be dressed from time to time, so that the 'minimum' diameter is usually several inches smaller than the 'new' diameter. The higher inertia of the larger-diameter rolls is small when compared with the total inertia of the drive, and consequently does not affect to any large extent the actual machine design.

The Company with which I am associated is the one mentioned by Mr. Peck as having applied amplidyne control to two old main drives.

XUM

The control equipments were fully tested when installed three years ago, but acceleration and top speeds were obtained in excess of mill requirements. These have now been reduced pending replacement of mill-motor and generator armatures, and are subject to the requirements of the mills. Although amplidyne equipments appear to be complicated, our staff are able both to maintain and adjust the equipments quite satisfactorily.

In regard to the insulation of armatures, etc., the machines with the two drives previously referred to, still have their original insulation, and very little trouble has been experienced.

The majority of winding troubles are caused by deterioration of insulation materials, due to inadequate bracing of coils or connections.

Ventilation of electric drives is a very large subject. The two primary alternatives, both of which require considerable maintenance, are :

(i) The ' straight through ' system, which requires very large cleaning arrangements

(ii) The ' closed circuit ' system, which needs only small cleaning arrangements for make-up air, but which requires large coolers and a large volume of clean cooling water.

The ' straight through ' air system has in the past been used mostly with an ' up-draught ' arrangement of air flow ; this usually results in uncomfortably high ambient temperatures in the Ilgner house. In a few cases we are investigating the possibility of ducting the hot air from the machines to the outside of the building.

I would suggest the use of refrigeration for cooling the very large volume of air of a closed system ; the wide temperature difference between the hot air from the machines and the refrigerated coolers would result in a better heat transfer. With this arrangement, all make-up air would be cleaned, as well as a proportion of circulating air, the result being a reduction in (*a*) the size of the cleaning and cooling equipment, (*b*) the volume of water required, and (*c*) the maintenance on both cleaners and coolers.

Mr. Peck's suggestion of separating the cooling air for generator and motor commutators from the rest of the machine is very sound, and I think that the ' down-draught ' scheme combined with refrigeration would result in a most compact and economic scheme.

Mr. **P. E. Peck** : I doubt whether Mr. Higson's suggestion regarding the use of refrigeration is a practical proposition. Under the most favourable conditions, the power required to drive the refrigerating machinery would be at least one third of the heat to be dissipated for any appreciable gain of temperature difference ; moreover, the heat taken up by the refrigerant (which includes the refrigerator drive power) has still to be dissipated in some form of cooler.

The use of refrigerated air has been investigated as a means of reducing the losses in turbo-alternators, but has not proved economically justifiable.

CORRESPONDENCE

Mr. **A. W. Shore** (Stewarts and Lloyds, Ltd.) wrote : At the Bilston Works of Messrs. Stewarts and Lloyds, Ltd., an electric drive for a 36-in. cogging mill (one of the first two such drives in Great Britain) was installed in 1907–08. The plant was manufactured by the Electric Construction Co., Ltd., of Wolverhampton, and consists of :

One Motor Generator Set—One 2000-h.p. 460/480-V. D.C. shunt-wound driving motor, coupled to *two* generators, each having a flywheel weighing about 32 tons and running at 325 r.p.m. One of these generators has an output of 1730/9920 amp. at 1000 V. and feeds the main mill motor. The second generator had an output of 1390/8000 amp. at 1000 V., and fed the 26-in. bar mill motor ; as, however, a new plant was installed for the bar mill in 1922/23, this generator is no longer in use.

Main Mill Motor—This has an output of 2000/1200 h.p. at 1000 V., being shunt wound, with interpole and compensating winding, and drives the mill through a $2\frac{1}{2}$ to 1 reducing gear. The motor attains a speed of 120/0/120 r.p.m. in $2\frac{1}{2}$ sec.

Bearing lubrication of mill motor and motor generator set is by gravity feed from an elevated storage tank.

Ventilation—The main mill-motor ventilation is by forced draught through a wet air filter, whilst the motor generator set has natural ventilation.

Insulation of Armature Coils—Mica and tape.

During the 43 years' life of this plant, the main mill-motor armature has been rewound on one occasion, and one new set of shunt fields has been fitted. The generator also has had its armature rewound, and a new set of shunt-field coils fitted.

It is interesting to note that the cogging mill recently broke all previous output records.

Mr. **J. L. Gaskell** (Appleby-Frodingham Steel Co.) wrote : I would appeal to the electrical manufacturers to devote considerably more attention to the reduction of noise from Ilgner sets and exciter sets. The present tendency to offer the comparatively cheap 750-r.p.m. sets does not help in this respect ; some old installations with lower speeds are appreciably less noisy than modern installations. In my opinion, the biggest single factor is the windage noise, and surely the knowledge now available on problems of air flow is sufficient for designers to be able to concentrate on making a very substantial reduction in this noise.

In regard to the series or parallel connection of generators (p. 316), the series connection gives the same torque but reduced speed of rolling in the event of one generator failing ; but with large single-armature mill motors surely the limitation of voltage between brush arms largely determines the parallel connection of generators ?

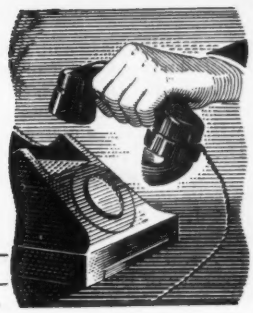
On p. 320 the author states that the D.C. circuit-breakers can be dispensed with if the generators are connected in series. I feel this would be a mistake; a positive means of breaking the main circuit between generators and mill motors is necessary, to enable men to carry out minor adjustments in the vicinity of the rolls without the necessity of shutting down the exciter sets.

The reference (p. 323) to pulpit arrangements opens up a big field. I feel there is scope for a full paper on this subject. If a desk is to be used (and I am sure this is desirable), all the main and auxiliary controls should certainly be co-ordinated. I consider that the initiative in this matter should be taken by the user, and not by the electrical manufacturers. I suggest, also, that the building of a full-size ' mock up ' is justified, bearing in mind the question of maintenance. If, however, the user is not prepared to expend a great deal of time and trouble over a desk layout, I suggest it is preferable to have all the controllers as separate items, the orientation of which can be altered easily.

Mr. Pool referred to the length of the control lever for the main-drive controller. Ours are $7–7\frac{1}{2}$ in. long, and we have no reason to believe that longer levers would be well received. Whatever kind of controller is used, operators are quick to detect any extra friction after renewal of contacts, etc.

(*Continued on p. 168*)

NEWS



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE
Autumn Meeting, 1951

The Autumn Meeting of the Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 21st and 22nd November, 1951.**

The programme is as follows :

Wednesday, 21st November

Morning Session

Joint Discussion on :
- "*The Crystal Structure of Graphite in Cast Irons*," by W. S. Owen and B. G. Street (Feb., 1951)
- "*The Carbide Phase in Iron–Carbon–Silicon Alloys*," by W. S. Owen (Feb., 1951)

Joint Discussion on :
- "*Metallography of Carbon in Silicon–Iron Alloys Containing 4% Silicon*," by E. D. Harry (Mar., 1951)
- "*The Variation in Electrical Properties of Silicon–Iron Transformer Sheet*," by S. Rushton and D. R. G. Davies (Mar., 1951)

Afternoon Session

Joint Discussion on :
- "*Symposium on Stresses in Moulds* " (July, 1951)
- "*Ingot Heat Conservation : Ingot Mould Temperature Measurements*," by R. T. Fowler and J. Stringer (Mar., 1951)
- "*Ten-Ton Ingot Moulds : Comparison of Design and Conditions of Use*," by A. Jackson (Mar., 1951)

Thursday, 22nd November

Morning Session

Joint Discussion on :
- "*The Production of High-Purity Iron and Iron Alloys on a 25-lb. Scale*," by B. E. Hopkins, G. C. H. Jenkins, H. E. N. Stone, and H. G. Short (Aug., 1951)
- "*Tensile and Impact Properties of Iron and Some Iron Alloys of High Purity*," by W. P. Rees, B. E. Hopkins, and H. R. Tipler (Oct., 1951)

Discussion on :
- "*Physical and Mechanical Properties of Segregates in Two Alloy Steels*," by H. M. Finniston and T. D. Fearnehough (Sept., 1951)

Joint Discussion on :
- "*Structural Transformation in the Tempering of High-Carbon Martensitic Steels*," by K. H. Jack (Sept., 1951)
- "*Magnetic Analysis of Iron–Carbon Alloys : The Tempering of Martensite and Retained Austenite*," by J. Crangle and W. Sucksmith (June, 1951)

Changes on Council

The announcement was made, at the Special Meeting of the Institute held in Austria, that Dr. J. Oberegger, General Manager of the Oesterreichisch-Alpine Montangesellschaft, has been appointed an Honorary Vice-President, in recognition of his distinguished services to the Institute.

Staff Changes

Mr. **Richard Elsdon,** Librarian of The Iron and Steel Institute for 47½ years, is due to retire on 31st December, 1951. A portrait and biographical details of Mr. Elsdon are given in the frontispiece to this issue of the *Journal*.

The Council have decided that Mr. **A. E. Chattin,** Assistant Secretary since 1925, should be Assistant Secretary and Librarian, and that Mr. **A. Post,** who joined the staff in 1946, should be Joint Assistant Secretary. These changes become effective on 1st January, 1952.

Andrew Carnegie Research Fund

An award of £250 for one year has been made to Mr. S. GARBER (Sheffield University) to enable him to carry out an investigation on " Graphite Formation in Cast Irons."

Binding Cases and Indexes for the Monthly Journal

Binding cases and Indexes to vols. 164, 165, and 166 are now available and are being dispatched to those Members who have applied for them.

Members are reminded that : (*a*) *Indexes* to the Monthly Journal are supplied *free on request* ; (*b*) *Binding* cases can be supplied at 10*s.* 6*d.* per set of three to cover the twelve monthly issues and that by special arrangement, Mr. W. A. Newark, 2, Clerkenwell Green, London, E.C.1, will bind Members' *Journals* at 10*s.* 3*d.* per volume, excluding cost of the binding case (new price applicable to volumes for 1950 onwards and all orders placed after 20th August, 1951) ; (*c*) *Holders* are available at 7*s.* 6*d.* each, in which up to four issues of the *Journal* and one index may be inserted for convenient handling. The above prices include postage.

NEWS OF MEMBERS

▶ Mr. S. BINNER has left Messrs. Stewarts and Lloyds, Ltd., Corby, to take up an appointment in the Atomic Energy Production (Ministry of Supply), Sellafield.

▶ Mr. T. BROOM has left the Division of Tribophysics, C.S.I.R.O., of the University of Melbourne, and is returning to England.

▶ Dr. J. CHIPMAN, Head of the Metallurgy Department at the Massachusetts Institute of Technology, has been awarded the Francis J. Clamer Medal in recognition of his contributions, as an individual and as a teacher, to the application of the theories of physical chemistry to steelmaking practice.

▶ Dr. M. COOK has been appointed Joint Managing Director of the Metals Division of Imperial Chemical Industries, Ltd., Birmingham.

▶ Mr. A. CROSBY has obtained the B.Sc. (Hons.) degree in metallurgy of the University of London.
▶ Mr. H. B. DARBY has been appointed one of the Iron and Steel Merchants' nominees on the Steel Consumers' Council, Ministry of Supply.
▶ Dr. D. W. DAVISON has taken up an appointment with T. S. Skillman and Co. Pty., Ltd., North Sydney, Australia.
▶ Mr. J. P. DENNISON has been appointed Lecturer in Metallurgy, University College, Swansea.
▶ Mr. J. DODD has received the B.Sc. degree of the University of Durham.
▶ Mr. N. F. DUFTY has left the Australian Iron and Steel, Ltd., and joined the staff of W. D. Scott and Co., in Sydney.
▶ Mr. G. E. DUNLAP, has left the Commercial Research Department of the American Brake Shoe Company.
▶ Mr. S. L. FINCH has been appointed to the Board of Directors of Catton and Co., Ltd., Leeds.
▶ Mr. S. GOODFELLOW has been appointed General Sales Agent for Messrs. N. M. Rothschild and Sons.
▶ Mr. HOBSON has left the Brown-Firth Research Laboratories to take up an appointment at Messrs. Hadfields Ltd., Sheffield.
▶ Mr. G. W. HORSLEY has left the Navy and joined the Metallurgy Division of the Atomic Energy Research Establishment, Harwell.
▶ Mr. F. A. HURST has been elected Chairman of Samuel Osborn and Co., Ltd., Clyde Steel Works, Sheffield, following the death on July 19th, 1951, of Mr. S. E. Osborn.
▶ Mr. K. R. JASTRZEBSKI has been awarded the B.Sc. honours degree in Metallurgy of the University of Swansea. He has taken up an appointment in the Research Laboratories of the Quasi Arc Co., Ltd.
▶ Mr. V. B. JOHN has been awarded the B.Sc. degree in Metallurgical Chemistry of the University of Wales.
▶ Mr. L. F. KORB has taken up an appointment as Associate Engineer with the Freyn Engineering Department of Koppers Co. Inc., Chicago.
▶ Mr. K. KUO has left the Royal Institute of Technology, Stockholm, to take up an appointment in the Department of Inorganic Chemistry of the University of Uppsala.
▶ Dr. H. LEE has taken up an appointment at the Institute of Metallurgical Research, Peking.
▶ Mr. R. E. LEVER has transferred to the Buenos Aires branch of Messrs. Richard Thomas and Baldwins, Ltd.
▶ Mr. G. LUCAS has been awarded the Ph.D. degree of the University of Durham.
▶ Dr. F. T. MCGUIRE has been appointed Manager of the Materials Engineering Department of Deere and Co., Illinois.
▶ Mr. N. H. POLAKOWSKI has been awarded an I.C.I. Research Fellowship tenable at the University of Swansea.
▶ Mr. P. POTTER has left the Royal School of Mines and taken up an appointment with H. J. Enthoven and Co., Ltd., Rotherhithe.
▶ Dr. J. N. PRATT has resigned his post as University Research Fellow in the Department of Metallurgy of the University of Birmingham to take up a similar appointment in the Department of Metallurgical Engineering, University of Toronto.
▶ Dr. G. V. RAYNOR has been appointed Visiting Professor of Metallurgy at The Institute for the Study of Metals, University of Chicago.
▶ Mr. R. W. ROBINSON has left the Central Metallurgical Laboratory, Emsworth to take up a new Admiralty appointment at H.M. Dockyard, Devonport.
▶ Mr. M. N. SAXENA is taking a training course at the Kulti Iron Works of the Indian Iron and Steel Company of the Martin Birn Group.
▶ Mr. P. W. SMITH has left Murex (Australasia) Pty., Ltd., Tasmania, and taken up an appointment as Examiner of Patents, Canberra.
▶ Dr. C. SYKES has been appointed Managing Director of Thos. Firth and John Brown, Ltd., not, of course, of the Brown-Firth Research Laboratories as stated in our September issue. Dr. Sykes has been Director of Research of the Laboratories since 1944.
▶ Mr. J. G. WISTREICH has been appointed Head of the Metal Working Laboratory of the British Iron and Steel Research Association.
▶ Mr. P. WRIGHTSON, O.B.E., Deputy Managing Director of Head, Wrightson and Co., Ltd., has been elected to a seat on the North Eastern District Board of Martins Bank Ltd.

Obituary

A. KIPGEN of the Société Anonyme, Luxembourg, on 11th August, 1951.

CONTRIBUTORS TO THE JOURNAL

E. A. G. Croom, M.A., Ph.D.—Holder of a research scholarship given by the South Wales Steel Sheet and Plate Manufacturers' Association in the University College of Swansea. Dr. Croom was educated at Jones West Monmouth School and at St. Catherine's College, University of Cambridge. After graduating in 1947, he studied under Dr. T. P. Hoar of the Department of Metallurgy at Cambridge, and in 1950 obtained the Ph.D. degree for his work on the formation of diffusion coatings on metals from metal chloride vapours. He is at present engaged in research on problems involving zinc and cadmium distillation.

A. K. Prestrud—In charge of the Raw Material Handling, Sintering, and Pig-Iron Plant of A/S Norsk Jernverk (Norwegian Iron and Steel Works under construction at Mo i Rana). Mr. Prestrud was born in Oslo in 1911. He graduated as a chemical engineer from the Technical University of Norway in 1934. After two years' research

A. K. Prestrud

E. A. G. Croom

work in the canning industry and at the Physical Institute of the Technical University of Norway, he joined Falconbridge Nikkelverk Aktieselskap, Norway, as a research chemist. From 1940 to 1948 he was engaged on the production of different ferro-alloys at Electric Furnace Products Company, Ltd., Norway. He took up his present position in 1948. Mr. Prestrud spent five months in Great Britain in 1944, one year in the U.S.A., 1944–45, and two months in Canada at St. Lawrence Alloys and Metals, Montreal.

IRON AND STEEL ENGINEERS GROUP

A Meeting of **Junior Engineers** will be held at Ashorne Hill on **Tuesday** and **Wednesday, 23rd–24th October, 1951.**

The programme will include a Lecture by Sir George Binney, D.S.O., on "The Importance of Commercial and Foreign Relations to the Steel Industry," and a talk on "Accident Prevention" by Mr. J. Brown of Messrs. Stewarts and Lloyds (Corby).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

London Laboratories

The Corrosion Section of the Chemistry Department, headed by Dr. J. C. Hudson, has now removed from Birmingham to the enlarged premises at 140 Battersea Park Road, London. These now house the whole of the Plant Engineering Division, the Chemistry Department, and the Physics Department.

Awards

Mr. P. H. SCHOLES of the Metallurgy Division (Bragg Laboratory) has been awarded a Licentiateship of the Institution of Metallurgists.

Mr. H. E. N. STONE of the Metallurgy Division, Park Lane, has been awarded an Associateship of the Institution of Metallurgists.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

The list of Officers for the Session 1951–52 is as follows :

President
L. A. S. PERRETT

Vice-Presidents
H. N. BOWEN — D. L. BLEWITT

Hon. Treasurer
U. WILLIAMS

Joint Hon. Secretaries
H. A. COOKE
M. J. A. THOMAS, B.Sc.

Council

Prof. H. O'NEILL, D.Sc., M.Met., (*Chairman*)
D. A. BISHOP
H. S. CASWELL, M.Sc.
R. G. DAVIES
R. W. EVANS, M.Met.
M. L. HUGHES, Ph.D.
G. D. JONES
D. G. NEWMAN
H. PHILLIPS
R. WALKER

Captain H. LEIGHTON DAVIES, C.B.E., has been appointed to represent The Iron and Steel Institute on the Council.

Liverpool Metallurgical Society

The list of Officers for the Session 1951–52 is as follows :

President
V. L. FARTHING

Vice-President
R. S. BROWN, M.B.E.

Past Presidents
H. EDWARDS — S. J. KENNETT, B.Sc., Ph.D.

Hon. Treasurer
H. J. MILLER, M.Sc.

Assistant Hon. Treasurer
G. T. CALLIS, B.Sc.

Hon. Secretary
J. A. PARDOE, M.Eng.

Committee

G. T. CALLIS, B.Sc.
T. H. FLETCHER
A. E. GRIFFIN
J. J. MILES
R. S. MOORE
S. V. RADCLIFFE, B.Eng.

INSTITUTE OF METALS

A general discussion on "Metal Economics," organized by the Institute of Metals, will be held at Park Lane Hotel, London, on October 17th, 1951. Members of The Iron and Steel Institute are cordially invited to attend. Among the papers to be presented is one by Dr. T. P. Colclough on "*Resources and Production in the Ferrous Field.*"

NEWS OF SCIENCE AND INDUSTRY

Structures of Silicate Minerals

A conference on the structures of silicate minerals, organized by the X-ray Analysis Group of the Institute of Physics, will be held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, London, W.C.2, on Friday and Saturday, November 2nd and 3rd, 1951. The programme is as follows :

November 2nd
2.15 P.M. Calcium silicates
8.30 P.M. Lecture on felspars by Dr. W. H. Taylor

November 3rd
9.45 A.M. Clay minerals and asbestos

Notch-Bar Testing in Relation to Welded Construction

The Joint Committee on Materials and their Testing in association with the Institute of Welding is holding a Symposium on Recent Development in Notch-Bar Testing of Materials and their Relation to Welded Construction, on Wednesday, 5th December, 1951, in London. Papers are being invited from a number of British and foreign experts.

Symposium on Mineral Dressing, 1952

Arrangements are now being made by the Council of the Institution of Mining and Metallurgy to hold a two-day Symposium on Mineral Dressing on 23rd and 24th September, 1952, at the Imperial College of Science and Technology, South Kensington, London, S.W.7.

The purpose of the Symposium will be to discuss recent developments (*a*) in fundamental concepts and experimental methods, (*b*) in practice at selected plants of particular interest, and (*c*) in plant design and machine manufacture.

Anyone who wishes to submit a paper is invited to send a synopsis of its contents and an indication of its probable length to the Secretary of the Institution, Salisbury House, London, E.C.2.

Kelvin Medal

The Kelvin Medal for 1950 has been awarded to Dr. Theodore von Karman, F.R.S., and will be presented to him in the Great Hall of the Institution of Civil Engineers on Tuesday, November 6th, at 4 p.m. Members of The Iron and Steel Institute are invited to attend the meeting.

World Metallurgical Congress

As a preliminary to the World Metallurgical Congress held in Detroit, Michigan, from October 14th to 19th, leading metal scientists from Marshall Plan and other non-communist nations were given the opportunity to visit more than a hundred major American metal-producing industrial plants to study their production methods. There were eight four-week study tours, arranged by the American Society for Metals, who also sponsored the Congress.

Conference on Heat Insulation

The Proceedings of the Conference on Heat Insulation held at the Institution of Mechanical Engineers on **30th November, 1950,** under the auspices of the Joint Committee on Materials and their Testing, have now been published. The text and full discussion of the papers "Heat Insulation in the Refrigeration Industry," "The Economics of Thermal Insulation in Building Construction," "High-Temperature Insulating Materials, their Properties and Testing," and "Medium-Temperature Insulation," are given.

Copies of the Proceedings can be obtained from The Secretary, The Institution of Gas Engineers, 17 Grosvenor Crescent, London, S.W.1, price 13*s.* 6*d.* per copy, post free.

North Wales Metallurgy Society

The List of Officers for 1951–52 is as follows:

Chairman

E. TAYLOR-AUSTIN

Treasurer	**Hon. Secretary**
S. ANDREW	S. WEIR
Assistant Secretary	**Hon. Press Secretary**
J. B. EDWARDS	P. R. HIGGINSON

Committee

H. BACON	C. LEWIS
H. EDWARDS	W. LLOYD
H. H. JOHNSON	J. T. SCOTT
H. LEDWARD	R. L. WILLOTT

Advisory Committee on Metals Economy

Mr. D. A. Oliver has been appointed Chairman of the Advisory Committee on Metals Economy, formed by the Ministry of Supply in conjunction with the Ministry of Materials. Among the industrial members of the committee are Dr. G. L. Bailey, Mr. W. C. F. Hessenberg, Dr. Ivor Jenkins, Dr. L. B. Pfeil, and Dr. C. J. Smithells.

Ore Carriers, Ltd.

Mr. D. H. Kyle, Sir Andrew McCance, and Mr. C. R. Wheeler are among the nine directors of the new company, Ore Carriers Ltd., formed by B.I.S.C. and the Houlder group to bring ore to Port Talbot and other ports in the United Kingdom.

Scrap Supplies

A report on scrap problems in Europe was made by the Steel Committee of E.C.E. in July.

Until about the end of the third quarter of 1950 the scrap supplies in Europe had been adequate but by 1951 there were signs of a shortage. The chief contributory factor was the inability to increase pig-iron production sufficiently rapidly to meet the increased demand, an inability caused by either lack of blast-furnace capacity or shortage of rich iron ore; this resulted in increased scrap consumption. The condition was general throughout the world and it would be necessary to increase ore consumption considerably to avoid a continued shortage of scrap.

It was essential to intensify scrap collection and the panel considered that unless its recommendations for new efforts were followed, the entire resources of scrap in Europe would not be exploited and this would have unfavourable repercussions on iron and steel production.

B.O.C. Prize for Welding Research

The Council of the British Welding Research Association gratefully accepted an offer from the British Oxygen Company, Ltd., in 1948, to provide for three years a prize fund for a competition relating to welding.

The first competition was held during 1948–49 but no award was made. In 1949–50, a prize was awarded to K. Winterton, C. L. M. Cottrell, and J. G. Ball for a joint paper entitled, "A New Weldability Test for Magnesium Alloy Sheet." The result for 1950–51 has not yet been announced.

As no award was made during 1948–49, a single prize of £100 is offered again this year and will be awarded for the best paper submitted on a research into welding or its application. Papers must reach the Secretary, British Welding Research Association, 29 Park Crescent, London, W.1 (from whom copies of the regulations governing the award may be obtained), on or before 31st December, 1951.

DIARY

10th Oct.—NORTH WALES METALLURGICAL SOCIETY—"*Some Notes on American Low-Carbon Steel Practice*," by C. H. Bacon and R. L. Willott—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

12th Oct.—LIVERPOOL METALLURGICAL SOCIETY—"*The Problem of the High-Temperature Oxidation of Metals*," by A. Preece—Electricity Service Centre, Whitechapel, Liverpool, 7.0 P.M.

15th–19th Oct.—AMERICAN SOCIETY FOR METALS—World Metallurgical Congress—Detroit, U.S.A.

17th Oct.—INSTITUTE OF METALS—"Metal Economics"—Park Lane Hotel, London, W.1.

22nd–27th Oct.—SOCIÉTÉ FRANÇAISE DE MÉTALLURGIE—Annual Conference—Paris.

TRANSLATION SERVICE

(The previous announcement was made in the September, 1951, issue of the *Journal*, p. 50).

TRANSLATIONS AVAILABLE

No. 424 (Czech). L. KUČERA: "The Colorimetric Determination of Silicon in Steel and Cast Iron." (*Hutnické Listy*, 1950, vol. 5, June, Supplement No. 2, pp. 102–106).

No. 425 (French). J. CYTHER and A. DENYS: "Note on the Operation on Run-of-Mine Ore of a Large French Blast-Furnace with a Hearth 6·5 Metres in Diameter." (*Revue de Métallurgie, Mémoires*, 1951, vol. 48, Feb., pp. 73–84).

TRANSLATION IN COURSE OF PREPARATION

The purpose of this announcement is merely to give advance notice of the intention to prepare translations, and orders should not be sent in until a further announcement appears under "Translations Available."

(German). H. POHL: "Investigations on Increasing the Output of Strand Sinter Plants." (*Stahl und Eisen*, 1951, vol. 71, June 7, pp. 597–605; June 21, pp. 664–669).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Mineral Resources of Soviet Russia. Sir Cyril S. Fox. (Mining Magazine, 1950, vol. 83, Oct., pp. 201–211). Estimated present production and reserves of mineral resources in the U.S.S.R. are reviewed, including petroleum, coal, and ores of iron, manganese, and many other metals. Many important materials and deposits are only mentioned by name. Figures are quoted from information given to the 1937 International Geological Congress, also data from the five-year plans. Geographical distribution of resources is outlined and geological relationships of some of the ores are indicated.—E. C.

Ore Deposits of Group 1a confirmed from Study of the Ferruginous Ores of the Asturian Paleozoic. P. Hernandez Sampelayo. (Instituto del Hierro y del Acero, 1951, vol. 4, Jan.–Mar., pp. 17–23). [In Spanish]. The grouping of the oolitic ores of the Asturian Devonian has already been indicated (*see* Journ. I and S.I., 1951, vol. 168, July, p. 305). The first group in the present article comprises four deposits along the coast from Cabo Peñas westwards to the zone of Pravia. This article describes the Areo and Carreño ores. The Peñas, Llumeres, and Ranón deposits are dealt with in a later article. The Areo and Carreño deposits are estimated at 9,000,000 tons containing 45% iron.—R. S.

Iron Mountain in Venezuela. (Jernindustri, 1950, vol. 31, July, pp. 109–111). [In Norwegian]. The discovery in 1947 of the Cerro Bolivar iron ore deposit means a very valuable addition to the resources of the U.S.A. Smelting plants will be erected in New Jersey. The cost per ton of ore, including the heavy item of transport, is estimated to be $8.54 which is competitive in comparison with that for low-grade ores in the U.S.A. since the Cerro Bolivar ore is very rich.—B. S. E.

Taconites Ore Ready. J. V. Beall. (Journal of Metals, 1950, vol. 188, Sept., pp. 1087–1088). The author discusses the necessity of developing the large taconite low-grade iron ore deposits in the Mesabi range (U.S.A.), in the light of the present-day diminution of high-grade reserves. The development of the jet-piercing drill by Linde Air Products Co. makes the project feasible, and the author considers that the most suitable method of concentration will be by pelletizing. The economics of the project are briefly considered.—G. F.

Brazilian Iron Ore Resources. R. G. Walker. (Blast Furnace and Steel Plant, 1951, vol. 19, Mar., pp. 337–338). The biggest known deposits at Corumba, Mato Grosso, are estimated at 50,000 million tons of proto-itabirite with 45–55% iron. In Minas Geraes there is estimated to be 15,000 million tons of itabirite with 30–60% iron, and 200 million tons of both compact and loose hematite with 60–70% iron.—E. J. B.

Cerro Bolivar—U.S. Steel's New Iron Ore Bonanza. M. C. Lake. (Engineering and Mining Journal, 1950, vol. 151, Aug., pp. 72–83). A general description is given of circumstances and events associated with the discovery of rich iron ore deposits in Venezuela at Cerro Bolivar and adjacent areas. The previous mining history and geology of the region are surveyed, followed by details of character, disposition, and size of the deposits. An outline of drilling exploration and development of the field is given, also plans for mining and shipment of the ore.—E. C.

ORES—MINING AND TREATMENT

The Mining of Minette in Lorraine. H. Prause. (Stahl und Eisen, 1951, vol. 71, Mar. 1, pp. 222–229). The geographical location and geological formation of the minette iron ore deposits in Lorraine, estimated reserves, mining costs, and the effects of mechanization in helping to overcome manpower shortages are described.—J. P.

Iron Ore in Great Britain. (Steel News, 1951, vol. 2, June, pp. 14–15). Past and present methods of working and smelting British iron ore are described.—T. E. D.

Sedimentation Cylinder for Particle Size Analysis. C. J. Leith. (Science, 1951, vol. 113, Apr. 13, pp. 412–413). A cylinder used for the separation of $\frac{1}{32}$–$\frac{1}{16}$ mm. grade size is described.—T. E. D.

Trends in Crushing and Grinding Practice in American Concentration Plants. S. Mörtsell. (Teknisk Tidskrift, 1949, vol. 79, Sept. 10, pp. 601–604). [In Swedish]. It is noticeable in American ore-dressing plants that there is a tendency to run ball and tube mills at a considerably lower speed than usual. This is generally considered to increase efficiency and reduce wear. Some types of impeller breaker and rod mills used as fine crushers are described.—B. S. E.

Cyclone Separator May be Solution for Fine Iron Ore Problem. S. E. Erickson and E. C. Herkenhoff. (Engineering and Mining Journal, 1950, vol. 151, June, pp. 71–73). Satisfactory pilot plant concentrates of minus $\frac{1}{4}$-in. iron ores were produced with a cyclone separator during trials by M. A. Hanna Co. and American Cyanamid Co. The flow scheme and operation of the pilot plant are described and results quoted. Efficiency of separation was 95–100% as compared with laboratory heavy-liquid separations. All sizes down to 100 mesh gave high-grade products, but no practical concentration was obtained in the minus 100-mesh sizes.—E. C.

The Use of Hydraulic Cyclones in Hematite Dressing. P. H. Fahlström. (Teknisk Tidskrift, 1949, vol. 79, Apr. 16, pp. 291–296). [In Swedish]. Hydraulic cyclones have been successfully applied to thicken hematite slimes before shaking-table dressing. The cyclones have large capacity, are simple to operate and yield thick pulps.—B. S. E.

A Tertiary Crusher for Soft Home Ores. C. Lang. (Journal of the Iron and Steel Institute, 1951, vol. 168, June, p. 164). Alternative designs for a multi-hammer mill for sticky ores are suggested. One incorporates a slowly moving breaker plate continuously rotating in the opposite direction to that of the high-speed hammers. The second design comprises two hammer-mill shafts side by side, one shaft being adjustable; the shafts rotate at high speed in opposite directions and the ore is fed into the gap between the two sets of hammers.

Modern Innovations and Evolutions in the Iron and Steel Industry. G. Bulle. (Instituto del Hierro y del Acero, 1951, vol. 4, Jan.–Mar., pp. 1–10). [In Spanish]. The author gives a general survey of developments in the beneficiation of Dogger and Siegerland ores, application of high top pressure in the blast-furnace, low shaft furnaces, rotary pig-iron furnaces, use of oxygen in iron and steel manufacture, continuous mills, and continuous casting.—R. S.

Heavy Density Separation Cuts Brown Ore Treatment Cost. S. A. Britton. (Engineering and Mining Journal, 1950, vol. 151, July, pp. 68–70). Details are given of the flow scheme and operation of a heavy-media cone concentrator for limonitic ores, operated by Sloss-Sheffield Steel and Iron Co., Alabama. The 10-ft. cone treats 40 tons/hr. of minus 3 in., plus $\frac{3}{8} \times \frac{1}{4}$ in. material screened from the log-washer product. Heavy medium (ferrosilicon) losses average 0·8 lb./ton of concentrate. There is 40% iron in the feed and 52% in the concentrate.—E. C.

Blackburn Heavy-Density Plant Opens New Brown Iron Ore Reserves. A. M. Shook. (Engineering and Mining Journal, 1950, vol. 151, Sept., pp. 78–81). Shook and Fletcher Supply Co. exploit near Russelville, Alabama, limonitic ores that are intermixed with cherts and gravels, necessitating beneficiation. Characteristics of the deposits and methods of mining are outlined. A flow scheme is shown of a washer and heavy-media beneficiation plant at Blackburn mine, using a 10-ft. cone with ferrosilicon medium.—E. C.

Blast Furnace Sintering Practice Surveyed. R. E. Powers. (Steel, 1951, vol. 128, Feb. 5, pp. 95–108). American sintering practice is surveyed but it is emphasized that no definite conclusions can be drawn because there are many operating variables. Qualitative properties required are, size sufficient for retention in the blast-furnace, uniformity of size, sufficient strength to retain that size, porosity, and reducibility at least equal to ore. The effects of fuel size, mixing devices, moisture, and air on the production of sinter are discussed.—A. M. F.

The Enrichment of Iron Ores by Magnetizing Roasting. V. I. Karmazine. (Centre de Documentation Sidérurgique: Circulaire d'Informations Techniques, 1950, vol. 7, Jan.–Feb., pp. 11–31). This is a translation from the Russian paper Gorny Zhurnal, 1946. The first part goes into the theory of magnetizing roasting by reduction. It shows that the magnetic susceptibility of a hematite, limonite, or siderite ore, initially little more than that of gangue, increases with decreasing oxygen content until the composition of magnetite is reached, after which it decreases again rapidly. By the oxygen potential method the necessary composition of gas to effect this reduction at any temperature is worked out, and the activation energy, required especially at low temperatures, is also calculated. The formulæ obtained are applied to the compact, quartzite-containing Krivoï-Rog ores. Some of these ores contain enough carbon to be self-reducing, at least as far as magnetite, and in other cases the ore is mixed with siderite, which evolves carbon monoxide at about 500° C. Otherwise water-gas is considered most suitable.

In the second half the structures and performances of furnaces for magnetizing roasting are illustrated and described. One is the Krivoï-Rog furnace, in which the ore finds its way down over seven circular shelves heated by burners on rotating arms. Another is a rotating kiln at Brunswick; it takes large and wet lumps, but suffers from big heat and dust losses, and is non-automatic. A shaft furnace of simple design at An Chan, Manchuria, is also described. It takes poor-quality fuels, and could be made automatic, but gives trouble with fine or sticky materials. Finally, there is the 'Cascade' type at Cooley, U.S.A., a shaft furnace into which the fines are charged separately down an alloy steel tube in the centre; this can also be made automatic, and is thermally efficient, though it needs careful control, and will not take much fines. The author considers the American furnace best adapted for lumpy ores, and the rotating kiln or mechanical types, more suitable for fine material.—N. McE.

The World's Largest Sintering Plant. W. J. Urban. (Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1951, vol. 39, Mar., pp. 339–342). The American Ore Reclamation Co. have constructed a sintering machine 12 ft. wide and 168 ft. long. It uses cast steel pallets and excessive wear of the pallet corners is avoided by using transition guides. The assembly is fixed at its midpoint to allow for longitudinal thermal expansion, amounting to $3\frac{1}{2}$ in. in the 168 ft. for a 300° rise. A saving of $0·179 ton for a production of 4500 tons/day of sinter is estimated when using a 12-ft. wide, 153-ft. long machine instead of three machines 6 ft. wide by 102 ft. long.—E. J. B.

Sintering Adirondack Magnetities. W. R. Webb and R. G. Fleck. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 671–672; Mining Engineering, 1950, June). Sintering of Adirondack magnetite concentrates on Dwight-Lloyd machines is described. About 5% anthracite, 65% concentrate, and 30% return fines are charged in that order on to a rubber belt and conveyed to a pug mill. After mixing, and raising the water content to 7%, discharge is by conventional swinging spout, depth of bed being $8\frac{1}{2}$ in. Ignition is oil-fired, at 1 gal. of fuel per ton of sinter. Length of sinterbelt is 102 ft. 8 in., speed of travel being variable between 65 and 130 in./min.—E. C.

The Sintering of Northamptonshire Iron Ore—A Production-Plant Study of Factors Affecting Sinter Quality. D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill. (Journal of The Iron and Steel Institute, 1951, vol. 167, Apr., pp. 400–439). The No. 3 sinter plant at the Corby works of Stewarts and Lloyds, Ltd., was made available to a team of investigators from the British Iron and Steel Research Association for full-scale experiments designed to determine the factors which control the quality of sinter made from Northamptonshire iron ores. In order to determine as far as possible a method of assessment of sinter quality, a rudimentary analysis was made of data on the use of sinter of known properties in the burdens of several blast-furnaces, and this emphasized the importance of physical properties. The effects and relative importance of the factors governing the physical properties of the sinter were determined. The control of proportions and properties of raw materials was most important, the carbon content of the raw mixture being especially critical. The efficiency of mixing and the exclusion of large fragments of ore and coke were next in importance, followed by control of content of returned sinter and of water in the mixed raw materials. Variations of suction had very little effect over the range of values encountered on the plant concerned.

Investigation of the Effects of Controlled Variables on Sinter Quality. Part I—Development of Experimental Sinter Plant and Preliminary Results Using Northants Ore. E. W. Voice, C. Lang, and P. K. Gledhill. (Journal of The Iron and Steel Institute, 1951, vol. 167, Apr., pp. 393–399). A sinter pan 2 ft. square was set up using suction from a production sinter plant, a separate fan being later erected to give controlled suction up to 32 in. W.G. Sinter was produced from weighed mixes, the sinter process was observed, and the sinter made was assessed for physical properties. Results showed agreement with previous data obtained on the full-scale sinter plant and, owing to the closer control and greater flexibiliy attainable with the small unit, quantitative results were achieved showing the effects of flue dust, returned fines, and coke on the sinter strength. Correlation was obtained between moisture content and suction on the speed of sintering, and observations were made of bed porosity and air flow before and during sintering. The effects of various fuels were also studied.

FUEL—PREPARATION, PROPERTIES, AND USES

The Evaluation of Various Fuels. F. Lüth. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 327–334). An attempt is made to develop a simple and general formula for comparing and evaluating one fuel as a substitute for another in metallurgical heating, annealing, and heat-treating furnaces. From the relationships derived, curves have been drawn from which

may be read, for a variety of industrial fuels as a function of the waste-gas temperature, the maximum possible price for the comparison fuel. Because of the multiplicity of factors involved in firing open-hearth furnaces, the relationships do not hold in this case.—J. P.

Steel Mill Fuels. O. P. Adams. (Industrial Heating, 1950, vol. 17, Dec., pp. 2152–2158). The constituents, properties, and problems encountered in the use of various fuels utilized by steelworks are discussed. Fuels considered are coke-oven gas, tar fuel, blast-furnace gas, and natural gas.—J. A. L.

Critical Examination of the Notion of Net Calorific Value. A. R. Sprega. (Calore, 1951, vol. 22, Feb., pp. 62–66). [In Italian]. The various and conflicting definitions of net calorific value given in the technical literature are considered and the reasons for these differences are discussed. Consideration is given to the possibility of arriving at a scientifically sound definition of this term.—M. D. J. B.

Control and Instrumention of an Experimental Furnace. G. W. Stein-Callenfels and R. Mayorcas. (Chaleur et Industrie, 1951, vol. 32, Mar., pp. 59–70). The establishment of an experimental furnace for the study of flame radiation is described. Details of the furnace and its modifications, and the instruments used for controlling and measuring flow of oil, combustion air, atomizing agents, and furnace pressure are given. The variables to be examined are the normal flame radiation on the surrounding cold parts, total transmission of heat, flame emission factor, temperature and radiation of the walls, and the composition and temperature of the flue gases. The equipment installed for these purposes is described. All instruments and thermocouples are calibrated and re-calibrated when necessary during the course of the experiments.—T. E. D.

Fuel Flow—Works Trial of a Metering Pump. A. L. Cude and J. Stringer. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 46–51). This paper describes the works trial of a metering pump installed on a 75-ton open-hearth furnace and operated for a total of approximately 400 hours. The pump gave much greater consistency of flow than normal hand-valve regulation, but this did not reduce the variability of the roof temperature. This variation is considered to be due to the dominating effect of manual control of the roof temperature. It is shown that the metering pump would offer a number of advantages over the conventional motorized valve, as a component of an automatic temperature controller. This application probably represents the most favourable direction for further development. The pump itself appeared to have suffered no undue wear as a result of pumping heavy fuel oil, but the stall-valve, employed to return the pump to zero setting automatically during reversal, was adversely affected by the accumulation of dirt. A method of eliminating the stall-valve is suggested. An electronic motor-speed control was used in these tests, and the possibility of replacing this by a simpler arrangement to compensate for speed variation is discussed. Speed compensation would be unnecessary if the pump were used as part of an automatic temperature controller.

Plant for the Recovery of Heat from Open-Hearth Furnaces. G. Tacchini. (Calore, 1951, vol. 22, Apr., pp. 141–149). [In Italian]. A description is given of the development and operation of a plant for utilizing the steam produced by open-hearth waste-heat boilers during the summer months. The steam is used to operate two steam-accumulator locomotives and also to feed a steam-operated compressor. A detailed description is given of the equipment for charging the accumulator locomotives. The locomotives can be charged to a pressure in excess of that in the waste-heat boilers.

Kerosene Flotation of Bituminous Coal Fines. L. E. Schiffman. (Mining Engineering, 1950, vol. 187, Oct., pp. 1047–1056). An account is given of two kerosene flotation plants, developed by the Sloss-Sheffield Steel and Iron Co., Alabama, for cleaning minus 10 mesh bituminous coking coals. One plant treats washer sludge, the other raw coal. Special adaptations of flotation cells are described, an overflow raking mechanism being substituted for the conventional froth paddle. Data on capacity, efficiency, and capital and operating costs are given.—E. C.

Rheolaveur System of Fine Coal Cleaning. J. Griffen. (Mining Engineering, 1950, vol. 187, Nov., pp. 1137–1138). Rheolaveur launders are claimed to clean effectively dirty coal produced by present-day mechanical mining methods. Some data are quoted in support, showing the size ranges handled, maintenance experience, and production figures on two-product and three-product separations.—E. C.

Some Recent Investigations with the Dutch State Mines Cyclone Separator on Fine Coal Slurries. S. A. Falconer. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 790–800; Mining Engineering, 1950, July). Practical application and commercial aspects of the Dutch State Mines cyclone separator for fine-coal cleaning are dealt with, also equipment required for operation. Important operating variables, their effects and means of control are discussed. Descriptions and results are given of a number of tests by American Cyanamid Co. with a 6-in. semi-commercial-size separator using various fine coals with finely ground magnetite as heavy medium. Details and data of the 50 ton/hr. plant in Holland are also given. Excellent separations are obtained in the size ranges of $\frac{3}{8}$ in. to 48 mesh.—E. C.

The Cleaning of Fine Sizes of Bituminous Coals by Concentrating Tables. R. E. Zimmerman. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 956–966; Mining Engineering, 1950, Sept.). The author describes and analyses results achieved on wet concentrating tables with unclassified bituminous coals of minus $\frac{1}{2}$-in. particle sizes, including tests on high-sulphur coals. The theory of wet tabling and factors influencing table action are discussed in brief. The Deister diagonal-deck table is described and shown to produce satisfactory results with unclassified coal fines. Efficient sulphur removal would require closely sized or classified feeds.—E. C.

Laboratory Performance Tests of the Humphreys Spiral As a Cleaner of Fine Coal. M. R. Geer, H. F. Yancey, C. L. Allyn, and R. H. Eckhouse. (Transactions of The American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 1057–1067; Mining Engineering, 1950, Oct.). Experimental treatment of four types of coal in a Humphreys spiral concentractor is described, and results are analysed. Float and sink tests and size analyses are used to assess fundamental performance characteristics. Efficiency of separation is shown to be influenced greatly by particle size, and retreatment of a combined refuse-middling product is suggested for maximum operational efficiency.—E. C.

Modern Coal Preparation Cuts Inland's Pig Iron Costs. (Steel, 1951, vol. 128, Jan. 29, pp. 74–80). A description is given of a new coal-preparation plant at Price, Kentucky, where raw coal can be sorted, crushed, washed, and blended at the rate of 750 tons/hr. This is expected to reduce ash by as much as 7%, resulting in a 10% lower slag volume in the blast-furnace, a 4% decrease in coke consumption, and a 4% increase in iron production.—A. M. F.

Modern Coke-Oven Development. (Iron and Coal Trades Review, 1951, vol. 162, Jan. 26, pp. 193–195). A description is given of the design and operation of the newly installed coking unit at the East Greenwich gasworks. The unit, consisting of two batteries of 22 ovens each, incorporates many new features, and has been designed for a total throughput of 1000 tons of coal/day, with provision for subsequent duplication of the unit. Descriptions of the producer-gas plant, the coal-handling plant, and the carburetted water-gas plant are also included.—G. F.

High Grade Coke and The Recovery of Waste Heat. I. Giordano. (Calore, 1950, vol. 21, June, pp. 211–220). [In Italian]. A detailed review is given of coking techniques developed over the last 25 years. The water cooling of coke is inefficient. This method of cooling produces a lower-grade coke of uneven size and is also extremely wasteful of heat energy. Other methods of cooling are examined and attention is given to means of producing high-grade coke and of recovering the large quantities of heat from hot coke. The theory of the dry cooling of coke is briefly developed and the advantages discussed. A detailed description is given of the Heller-Bamag, Collin, and Sulzer methods.—M. D. J. B.

Problems of Economical Utilization of Coke-Oven Gas in the U.S.S.R. B. J. Kustov and O. N. Vajsberger. (Za Ekonomiu Topliva: Hutnické Listy, 1951, vol. 6, Jan., pp 42–43). [In Czech]. The planned coke production in the U.S.S.R. in 1950 was 30 million tons, which corresponds to about 11,000 million cu. m. of coke-oven gas. Since this is a high-quality gas, great efforts are made to economize in its use, particularly for heating the coke ovens. Blast-furnace gas is being used for heating these and it is proposed that producer gas be used where blast-furnace gas is not

available ; coke breeze can be used as a raw material for the producer gas. A coke-oven gas pipeline grid is also envisaged, particularly in the industrial Donbas area.—E. G.

Sonic Agglomeration of Fume in Ferro-Manganise Blast-Furnace Gas. A. H. Brisse. (Industrial Heating, 1950, vol. 17, Nov., pp. 1966–1972). An investigation to determine the practicability of sonic agglomeration of fume is reported. The equipment and method of testing are given. Test results give effective frequencies, minimum values of sound pressure, and minimum retention time in the sound chamber. The results indicate that sonic energy can be effectively used for fume agglomeration.—J. A. L.

TEMPERATURE MEASUREMENT AND CONTROL

Fusible Cylinders as Temperature Indicators. K. W. Frohlich. (Werkstatt und Betrieb, 1950, vol. 83, June, pp. 275–276). A series of fusible alloys known as TKK (*Temperaturkennkörper*) alloys has been developed for use in indicating temperatures between 130 and 1100° C. (and for some higher temperatures) in steps of 10° C. They are generally used as cylinders 12 mm. in dia. and 16 mm. high or 6 mm. in dia. and 15 mm. high. The use of a set of cylinders for nominal temperatures covering a small range in the neighbourhood of the required temperature is a convenient aid to temperature control. They are particularly useful in any type of heat-treating furnace in which the parts move through the furnace, the cylinders being placed on the parts themselves. The cylinders show obvious signs of softening at their nominal temperature and melt down completely in a few minutes if this is exceeded. Their accuracy of indication is 17° C. The normal alloys are intended for use in oxidizing atmospheres, and special alloys have to be used in other atmospheres.—H. R. M.

Study of Industrial Flame Radiation—The Experimental Furnace at Ijmuiden. M. Michaud and M. Rivière. (Revue Générale de Mécanique, 1950, vol. 34, Nov., pp. 414–421 ; Dec., pp. 445–450). Methods for measuring heat exchange, including thermocouples, optical pyrometers, total radiation pyrometers (direct ray and mirror types) and for gas analysis and flame contour measurements are described.—R. S.

Temperature Control in Industrial Furnaces. L. Padoa. (Rivista di Meccanica, 1951, vol. 2, Mar. 10, pp. 5–10). [In Italian]. A review is given of the methods available for furnace temperature measurements. After a brief consideration of primitive visual methods of assessing temperature the author gives a classification of types of instrument and then describes in detail the common mercury thermometer, the inert-gas mercury thermometer, the quartz mercury thermometer, long-range thermometers, thermocouples, resistance thermometers, thermoelectric and optical pyrometers, evanescent filament and constant-current pyrometers, and lastly the Féry, Kaiser, and Schmidt types.—M. D. J. B.

Radiation Pyrometry in the Steel Industry. D. Robertson. (Mechanical Engineering, 1951, vol. 73, Mar., pp. 198–202). This is an elementary and brief account of the radiation pyrometer, what it is, how it works and its use in steelworks. The latest instruments are described.—D. H.

The Use of the Immersion Pyrometer with Bessemer Converters. M. Tavard. (Centre de Documentation Sidérurgique : Circulaire d'Informations Technique, 1949, vol. 6, Nov.–Dec., pp. 506–513). Readings of a Land-Tinsley immersion pyrometer were compared with those of an optical pyrometer, which were lower by an average of 87° C. The temperatures at the end of blowing and during teeming were measured under various conditions, and the value of the former, which gave the best crack-free ingots, was found. A suitable carriage for the immersion pyrometer, free from vibration and protected from sparks, is called for.—N. McE.

Variations in the Readings of Temperature Indicators. A. Barthel. (Werkstatt und Betrieb, 1950, vol. 83, June, p. 274). If the resistance of the external circuit of a thermocouple-type temperature indicator differs from the value used for calibration, there will be an error in the reading. One cause of variation in resistance is the heating up of the thermocouple wires themselves, particularly if they are made from materials having a high-temperature coefficient of resistance, *e.g.*, platinum and platinum–rhodium. When such thermocouple materials are used over a wide range of temperature, these errors can be minimized by using instruments with sufficiently high internal resistance.—H. R. M.

The Control of Electric Element Furnaces to Fine Limits at High Temperatures for Research Purposes. T. W. Lomas, M. D. Jepson, and J. R. Rait. (Journal of The Iron and Steel Institute, 1951, vol. 168, June, pp. 126–134). In the measurement of creep a degree of accuracy greater than $\pm$ 0·10° C. is required if reproducible results are to be obtained. The paper discusses various types of controller, and a commercial resistance thermometer/thyratron instrument is shown to be the most suitable on the grounds of cost, availability, and performance. The range of this instrument is shown to be limited by the properties of the resistance thermometer used ; various types are described and their useful ranges are stated. The use of special types of resistance thermometer or thermistor enables the range to be extended up to 1500° C. with only slight modifications to the controller.

Calibration Furnaces for Total-Radiation Pyrometers. E. J. Burton and R. Mayorcas. (Journal of The Iron and Steel Institute, 1951, vol. 168, June, pp. 151–155). The essential requirements of a furnace for calibrating total radiation pyrometers in the temperature range 1000–1750° C. are (*a*) that it emits radiation which is substantially that of a black body ; (*b*) that it provides a sufficiently large source (at least 3 in. dia. for existing industrial pyrometers) ; and (*c*) that the temperature of the furnace may be rapidly changed within the range of calibration. An electrically heated graphite-tube furnace 36 in. long and 3 in. internal dia., which satisfies these conditions, has been constructed, but the large current (1400 amp.) required to heat the tube demanded a special transformer installation. A second furnace requiring only 150 amp. has been built. In this the resistance is increased by cutting the tube to form a grid. The emissivity of the radiating source has been increased by grooving its surface. Alternatively, a bundle of thin-walled graphite tubes, each acting as a black body, has been used as the black radiator ; the length of furnace required at a uniform temperature is then reduced to the length of the tubes.

REFRACTORY MATERIALS

Fusion Cast Refractories. H. Moore. (Ceramics, 1950, vol. 2, Oct., pp. 405–410 ; Nov., pp. 462–467). Principles, properties, and production of fusion-cast refractories are described in detail. Mixes containing more alumina than mullite are used to obtain a glassy matrix high in alumina. Héroult electric melting furnaces are used, the molten charge providing resistance heating after initial arc heating through a coke layer. 'Corhart' refractories are made from natural bauxites, 'ZAC' types from high-purity artificial alumina and zirconia mixes. 'Monofrax' types have very low proportions of glassy matrix, crystalline constituents being variously beta-alumina, corundum, and, in special types, iron and chromium spinels. Fusion-cast refractories have low porosity, high thermal conductivity, low thermal expansion, and high corrosion resistance. Spalling resistance is comparatively low, making them unsuitable for processes with large cyclic temperature changes.—E. C.

A Carbon Resistance Furnace for P. C. E. Tests. H. E. CoVan and J. L. Carruthers. (American Ceramic Society Bulletin, 1951, vol. 30, May, pp. 170–173). The Orton Foundation granular carbon furnace for checking Seger cones is described and some results obtained given.—R. A. R.

Zircon Refractories. (B.C.U.R.A. Quarterly Gazette, 1951, No. 12, pp. 4–6). Zirconium silicate refractories will withstand temperatures up to 1800° C. and are more resistant to attack by siliceous slags than sillimanite. Additional advantages are their resistance to thermal shock and spalling, and their low thermal conductivity. References are given to patents covering several manufacturing processes.—T. E. D.

Fireclay from the Obwetti Colliery, Nigeria. (Colonial Geology and Mineral Resources, 1950, vol. 1, No. 4, pp. 327–331). A sample was examined and found to be a high-silica fireclay, characterized by variations in the grain size of the associated quartz from sub-microscopic dimensions to over 1 mm. in dia. Some pottery was produced, the fired and unglazed ware having a high porosity. The clay does not possess marked refractory characteristics.—T. E. D.

Statistical Study of Results of Tests on Silica Bricks. M. Baron. (Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1950, vol. 7, No. 3–4–5, pp. 171–188). Many laboratory tests on silica bricks are statistically

examined. Mechanical strength, heat resistance, resistance to thermal shocks, changes of dimensions under prolonged exposure to high temperatures, and dilatation up to 1000° C. are tabulated and also graphically represented. The limitations of the method are explained. A brick which under a standard stress of 28·4 lb./sq. in. flows by no more than 0·5% above 1615° C., with an absolute density of 2·36, and free from quartz is likely to be of high quality.—P. F.

Semi-Silica Refractories Lessen Furnace Structural Failures. G. B. Remmey. (Steel, 1950, vol. 127, Nov. 27, pp. 62–68). Semi-silica refractories have a high resistance to structural spalling and high resistance to plastic flow at temperatures encountered in recommended uses. It is suggested that this is due to the checking of slag penetration by the formation of a covering glaze very high in silica. The composition of this brick is so close to the eutectic that only a small pick-up of fluxes is necessary to fuse the surface. The plastic flow resistance, thermal spalling, and expansion of semi-silica brick are compared with those of clay and silica brick.—A. M. F.

Treatment of Bricks to Prevent Carbon Monoxide Disintegration. J. A. Shea. (Chicago District Blast Furnace and Coke Association and Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1951, vol. 39, Mar., pp. 333–336). See Journ. I. and S.I., 1951, vol. 168, July, p. 307).

The Evolution of the All-Carbon Blast-Furnace. J. H. Chesters, G. D. Elliott, and J. Mackenzie. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 273–282). The use of carbon bricks in the blast-furnace is traced from the early hearth experiments, designed to minimize breakouts, to the present stage of three all-carbon blast-furnaces at Appleby-Frodingham. The properties of carbon bricks and the essential design features of carbon hearths are discussed in detail. It is concluded from operating evidence and from the results of examination of blown-out hearths that carbon is successful in preventing breakouts. Trials of carbon bricks in bosh and stack are described with particular reference to scaffold formation. Operation and cost details of No. 6 furnace, Appleby-Frodingham, blown-in in April, 1949, and of No. 1 and No. 5 furnaces, which were later relined in carbon and blown-in in October, 1949, and April, 1950, respectively, are discussed. In spite of burden handicaps, in the first year of operation No. 6 furnace made 12%, and No. 1 furnace 4%, more iron than in the first year of the previous campaigns.

Blast-Furnace Hearths of Rammed Carbon. F. Millan. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 210–222 ; Oct.–Dec., pp. 282–287). [In Spanish]. The requisite properties of blast-furnace refractories are stated. The development of carbon hearths is reviewed and details of the German and Spanish methods of construction are described. In the second part the cost of alumina brick construction and that of a carbon ramming mass for the hearth and bosh of a 400-cu. m. furnace are compared. German and Spanish methods of preparing the carbon paste are described, with some cost figures in the Spanish case relating to the Sestao furnace of the Altos Hornos de Vizcaya.—R. S.

The Behaviour of Blast-Furnace Refractory Linings in Contact with Slag. Y. Letort. (Silicates Industriels, 1951, vol. 16, Apr., pp. 99–104). The physical, physicochemical, and chemical causes of the deterioration of blast-furnace refractories are discussed with particular reference to the papers " Temperature Gradients through Blast-Furnace Linings " by G. R. Rigby and co-workers, and " The Application of Certain Tests to the Study of the Action of Blast-Furnace Slags on Refractory Materials " by W. Hugill and A. T. Green. The factors to be considered in the choice of brick are considered, and an alumina content of about 40%, is recommended for most parts of the furnace. The strength of slag–brick mixtures is least if the slag content is 75%, and the deterioration most rapid at about 1150–1200° C.; cooling some parts of the furnace is recommended as effective counteraction.—P. F.

Refractory Linings by Pressure Gun. H. N. Acker. (Canadian Metals, 1951, vol. 14, Mar., p. 25). A description is given of the ' Bondactor ' process whereby any refractory mixture for patching or lining is applied by pressure gun. The mixture is metered and fed dry to the gun nozzle where it is hydrated by atomized spray. Linings of high density and low moisture are produced at greatly reduced labour costs. Use of firebrick is entirely eliminated.—E. C.

Refractories for the Steel Industry. (Ceramics, 1950, vol. 2, Aug., pp. 285–293). A general account is given of the methods and products of Thos. Marshall and Co. (Loxley) Ltd. Production techniques include new power and labour-saving methods of vacuum de-airing clay. Some data are given on alumina and vermiculite thermal insulating bricks and Carblox carbon refractories.—E. C.

Experiments on Forsterite Linings Reported Successful. B. M. Pearson. (Iron Age, 1951, vol. 167, Jan 18, pp. 65–67). The author reviews German literature on forsterite linings and shows that the Germans have had good results with them in induction furnaces. The raw material, Norwegian olivines, is used to make a compound consisting principally of 50·8% MgO and 40·7% SiO_2 which is highly refractory and free from transformation changes. Tests have shown that forsterite linings do not crack or fissure, effectively minimizing the danger of breakouts.—A. M. F.

Stabilized Dolomite and Its Applications in the Iron and Steel Industry. M. Guédras. (Métallurgie, 1950, vol. 83, Nov., pp. 835–841). The properties and chemical compositions of dolomite are described. The object of stabilization is to obtain a dolomite which is not affected by the humidity of the air and by recarburization. Nierenstein started from the principle that it is possible to stabilize a molecule of CaO by forming $CaO.SiO_2$ or by neutralizing lime by the Fe_2O_3, but he committed a serious error in that $CaO.SiO_2$ forming wollastonite or pseudo-wollastonite whose melting point is 1512° C. cannot resist the temperature of open-hearth and electric furnaces. Chesters' idea was to transform the lime molecule into calcium trisilicate which is stable above 1900° C. and below 1250° C. The various applications of dolomite for furnace lining are described.—R. S.

Manufacture of Graphite Crucibles. H. P. S. Murthy and R. Singh. (Journal of Scientific and Industrial Research. 1951, vol. 10A, Mar., pp. 114–117). Indian crucibles up to size 60, made from Ceylon crystalline graphite manually crushed to between 20 and 90 mesh and bonded with clay, give good service for cast iron but are unsuitable for non-ferrous metals or steel. The crucibles are made manually from a wooden or machined cast iron mould and a plunger, and the methods of drying-out have not yet been standardized. The glazing, a felspathic glass high in manganese dioxide, is not made to fit each individual body but the firing in a coal-fired, down-draught kiln for 24–30 h.p. has proved satisfactory.—E. J. B.

New Industrial Material. (Scope, 1951, June, pp. 86–89). Vermiculite, hydrated magnesium aluminium silicate, has extensive industrial uses in its exfoliated form. In building it is used to replace aggregate in concrete and sand in plaster. ' Vermiculite concrete ' is used for thermal insulation of roofs and floors, and ' vermiculite plaster ' is used as a finish for walls and ceilings and for fireproofing structural members. In industry it is often used in granular form as a thermal insulator. It is also employed for horticultural purposes. A list of firms producing or marketing this material is included.—T. E. D.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Improvement of the Heat Exchange in a Cowper Stove by Modification of the Gas Flow. M. Boissin. (Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1950, vol. 7, Jan.–Feb., pp. 39–50). Rapid pulsations in the gas flow to a stove at the works of the Compagnie des Hauts-Fourneaux de Chasse were found to correspond with the time taken for sound waves to travel up and down the combustion chamber, and also along a section of the gas main, so that resonance was established. This caused a high intermittent gas velocity which led to a Reynolds Number exceeding the critical value at one part of the checkerwork. The resulting turbulence is said to be the reason for the lower chimney temperature and higher thermal efficiency obtained with this stove.—N. McE.

Is the Reduction of Iron Ore by Hydrogen a Commercial Possibility ? P. E. Cavanagh and H. W. McQuaid. (Metal Progress, 1951, vol. 59, Apr., pp. 523–526). This is a symposium of two points of view. Cavanagh feels it is doubtful, because the reduction of iron oxide by hydrogen needs additional heat, causing temperature gradients which would lead

to difficulty in practice ; this would not be easy with a blast-furnace. Reference is made to E. Smith's paper " Experience to Date on Iron Production by Methods Other Than Coke Blast Furnace " (Journ. I. and S.I., 1948, vol. 160, Oct., p. 220). In reply McQuaid suggests that the problem of heat introduction can be solved by passing preheated hydrogen through the ore, and emphasizes that the ore must be finely divided, of magnetite or pyrite, and that an essential is the new and cheap method of producing bulk hydrogen.—E. T. L.

Solution Loss and Reducing Power of Blast-Furnace Gas. T. L. Joseph. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 191, pp. 37–43 ; Journal of Metals, 1951, Jan.). The author describes a study of blast-furnace reactions made to determine the amount of solution loss necessary to maintain the reducing power of the gas stream in the furnace. Curves are presented to show the effect of solution loss, moisture in the blast, and carbon dioxide from the flux on the nitrogen content of the top gas, in the particular practice at the author's works.—G. F.

Reduction Experiments with Magnetite and Hematite Crystals. S. E. Eriksson. (Teknisk Tidskrift, 1950, vol. 80, May 13, pp. 449–450). [In Swedish]. The porous wüstite structure obtained on reduction of hematite explains the high reducibility in comparison with magnetite.—B. S. E.

Germans Make Pig Iron without Coking Coal. B. M. Pearson. (Iron Age, 1951, vol. 167, Jan. 11, pp. 71–72). A description is given of the experimental work carried out in Germany with the Humboldt distillation process for producing pig iron in a low-shaft blast-furnace. Briquettes made of non-coking coal and ore fines are used, low-temperature carbonization taking place in the upper part of the shaft, and reduction and melting in the middle and lower part. The furnace may be rectangular or round, 13 to 17 ft. high, and has an output per unit volume three times that of a conventional blast-furnace with a similar burden.—A. M. F.

The Use of Lignite for Smelting Pig Iron. N. Sjögren. (Stahl und Eisen, 1951, vol. 71, Apr. 12, pp. 388–391). Trials have shown that it is possible to smelt iron with Styrian lignite in an electric low-shaft furnace. In addition, successful results have been obtained in smelting Styrian ore with Styrian lignite in an oxygen low-shaft furnace. Some 1200 tons of iron have been produced in this way. The price of electric power will decide which of these methods is the more suitable for use in Austria.—J. P.

Pilot-Plant Smelting of Ilmenite in the Electric Furnace. C. K. Stoddard, S. S. Cole, L. T. Eck, and C. W. Davis. (United States Bureau of Mines, 1950, Report of Investigations No. 4750). A fairly large-scale test on the removal of iron from ilmenite ($FeTiO_3$) ore by electric smelting has been successfully carried out. The material produced was suitable for the production of titanium dioxide pigment in the usual plant facilities. Pig iron was produced as a by-product, an average analysis being 3·85% C, 0·69% S, and 5·16% Si. Methods are suggested for desulphurizing the iron before marketing.—B. G. B.

The Mechanism of Sulphur Transfer between Carbon-Saturated Iron and CaO–SiO_2–Al_2O_3 Slags. G. Derge, W. O. Philbrook, and K. M. Goldman. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1111–1119 ; Journal of Metals, 1950, Sept.). Results are presented of a laboratory investigation of the mechanism of sulphur transfer, and the factors determining its rate, between molten iron saturated with carbon and slags of the CaO–SiO_2–Al_2O_3 system. It is shown that the area of slag–metal interface is a determining factor in the rate of sulphur transfer, and that diffusion of sulphur in the slag at 1600° C. is so slow that concentration gradients are eliminated by convection rather than by diffusion. The experiments confirm that desulphurization under reducing conditions takes place in the following stages: (1) $FeS_{(metal)} \rightleftharpoons FeS_{(slag)}$; (2) $FeS_{(slag)} + CaO_{(slag)} \rightleftharpoons FeO_{(slag)} + CaS_{(slag)}$; (3) $FeO_{(slag)} + C_{(metal)} \rightarrow Fe + CO_{(gas)}$. The rate of CO evolution accompanying the reaction increases with temperature and with the sulphur content of the iron.—G. F.

Working a Large French Blast-Furnace, 6·5-m. Hearth Diameter with " Run-of-Mine " Ore. J. Cyther and A. Denys. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Feb., pp. 73–84). Constructional and working details of the furnace are given. Owing to the incompletion of the crushing plant ' run-of-mine ' ore has had to be charged. Contrary to expectations, the furnace has operated smoothly for eight months, producing an average of 513 tons of iron per day with a daily coke consumption of 450 tons. A materials balance for 1949 is given, and the reasons for this regular working discussed. [This paper has been translated, *see* Iron and Steel Institute, Translation Series, No. 425].

Significance of Equilibrium and Reaction Rate in the Blast-Furnace Process. J. B. Austin. (Journal of The Iron and Steel Institute, 1951, vol. 167, Apr., pp. 358–363). The blast-furnace process comprises a series of reactions which are delicately balanced so that it operates at a substantially steady state. On the basis that all the reduction is ' indirect,' it is possible to set up a thermodynamically ideal, isothermal process, operating at minimum consumption of carbon. Comparison of this minimum with the amount of carbon required as fuel indicates that in a furnace producing the common grades of iron from Mesabi ore the requirement for carbon is determined primarily by the need for a reducing agent. The reaction between slag and metal in the hearth is not at equilibrium in respect to sulphur. The operation of the furnace is influenced by the effective rate of a number of reactions, such as the reduction of iron oxide, the dissociation of limestone or moisture, and the ' solution ' of carbon.

Full-Scale Blast-Furnace Trials. J. A. Bond and T. Sanderson. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 24–39). A study has been made of full-scale trials carried out at the Appleby-Frodingham and Workington branches of The United Steel Companies, Ltd. Details are given of selected trials, showing the benefits to be derived from better selection and preparation of raw materials, ore, and coke, and from the use of increased amounts of sinter in the burden. Brief reference is made to attempts to improve the distribution of the burden by alteration of design and to accelerate reduction by means of steam injection, thereby promoting smoother blast-furnace operation and increased output at a lower coke consumption. The main object of the paper, however, has been to demonstrate that full-scale trials are practicable in a large organization without undue disruption of the normal routine and output of the plant. It is emphasized that such trials require careful planning and subsequent statistical interpretation.

Pressure Operation of Blast Furnaces—1950. R. P. Liggett. (American Iron and Steel Institute : Blast Furnace and Steel Plant, 1951, vol. 39, Mar., pp. 324–326). Elevated top pressures of up to 12 lb./sq. in., obtained by introducing a choke valve in the outlet gas piping after the gas washer, have been operated on Republic Steel Corporation furnaces at Buffalo, Chicago, Warren, and Youngstown. A 5-stage blower which uses 20% more steam and delivers its output at 35 to 40 lb./sq. in. is required. Although lost time is increased by 10 to 20%, flue dust-production is cut by half. At Youngstown No. 3 furnace production increased from 1070 tons/day in 1947 to 1121 tons/day in 1950.—E. J. B.

Low-Temperature Coke As a Reactive Carbon. C. E. Lesher. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 187, pp. 805–810 ; Mining Engineering, 1950, July). Extensive studies are reported of the reactivity of coke at 950° F. and 1650° F. as measured by relative rates of reduction of iron oxides at temperatures up to 2200° F. The gaseous nature of reduction by carbon is confirmed. Agglomerates, in which the iron oxide was intimately associated with the carbon, were the most reactive, coke being the least reactive of the carbons tested. Agglomerates reacted more rapidly and at lower temperatures than mechanical mixtures.—E. C.

TREATMENT AND USE OF SLAGS

Blast-Furnace Slag Lime for the Nutrition of Plants. W. Ebert. (Stahl und Eisen, 1951, vol. 71, Apr. 12, pp. 391–393). The loss of minerals from the soil by washing out with rain and harvesting of crops is not restricted to nitrogen, potassium, phosphorus, and lime. The essential trace elements, whose absence causes deficiency diseases, are also lost. Blast-furnace slag lime provides active lime, all the desirable trace metallic elements and, additionally, silica in forms readily assimilated by plants.—J. P.

A New Light-Weight Building Material from Blast-Furnace Slag. F. Schmidt. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 351–353). ' Siporex ' porous gas concrete is made from sand, cement, and water with the addition of aluminium powder to act as a gas-evolving reagent for producing the pores.

The hardening of the concrete takes place in steam autoclaves. Finely ground blast-furnace slag, according to its composition, can replace some or all of the sand and some of the cement. In the autoclave, the lime and silica become reactive and form the desired end-products. The use of Siporex for reinforced building units is discussed.—J. P.

The Use of Blast-Furnace Slag in the Cement Industry. G. Mussgnug. (Stahl und Eisen, 1951, vol. 71, Mar. 15, pp. 294–297). Basic blast-furnace slag can advantageously replace a high proportion of Portland cement in concrete mixes and so economize in power for the preparation and drying of cement clinker. It is stated that it is railway freight charges which prevent blast-furnace slag being sold at a price satisfactory to producer and consumer.—J. P.

Plants for Processing Blast-Furnace Slag in the Soviet Union. M. Mikovec. (Technická Práce, 1950, vol. 6, Jan., pp. 10–11). [In Czech]. Plants to produce cement and gypsum from blast-furnace slag are under construction in the U.S.S.R. One of these with an area of 19,000 sq. m. is described with drawings of the layout.—E. G.

Chemical and Petrographic Examination of Alkaline Slag. M. I. Nekrich and L. I. Karyakin. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 74, No. 4, pp. 795–797). [In Russian]. The results of chemical and petrographic examinations of alkaline slag obtained during the desulphurization of pig iron by the soda ash process, are described.—V. G.

DIRECT PROCESSES

Electrothermic Process of Steelmaking. C. Tama. (Tecnica e Industria, 1951, vol. 29, Apr., pp. 276–278). [In Spanish]. The process for producing steel direct consists of the reduction of iron ore by the carbon and other elements contained in a bath of pig iron heated by induction. The method is offered as a partial solution to the scarcity of metallurgical coke in Argentina. One or more induction furnaces and a cupola are used. Pig iron is melted in the cupola and transferred to the induction furnaces. Ore is added. Alternatively, cold pig can be melted in the induction furnaces and 60–70% of steel scrap can be added. Additional refining is effected by oxides such as ore, pyrites ash, ferruginous sands, mill scale, etc. Ingots or slabs are teemed from the furnace. The main reaction is: $14Fe_2O_3 + 30C = 12CO_2 + 18CO + 28Fe$, *i.e.*, 1568 kg. of iron are incorporated in the bath for each 360 kg. of pig-iron carbon. Advantages of this method over the use of carbonyls for powdered iron, and over rotary furnaces, hydrogen reduction, arc furnaces, and electric low-shaft furnaces, are clearly stated.—R. S.

Production of Sponge Iron in the Tunnel Furnace. P. E. Cavanagh. (Metalurgia y Electricidad, 1950, vol. 14, Dec., pp. 44–47). [In Spanish]. The production of sponge iron in the tunnel kiln normally used for refractory bricks is surveyed. A considerable labour force is required but it need not be specialized. The process can be used only for small quantities and where coal is cheap. The Wiberg-Söderfors process was found to be the most efficient subject to certain stated conditions. The trials were carried out in Canada.—R.S.

Production of Sponge Iron in Tunnel Furnaces. S. Eketorp and P. E. Cavanagh. (Värmländska Bergsmannaföreningens Annaler, 1950, vol. 1, pp. 61–98). [In Swedish]. A modification of the Höganäs process for producing sponge iron in covered crucibles fired in ordinary tunnel brick kilns is described and compared with the Wiberg-Söderfors method. The following conclusions are drawn from the authors' experience of the Canadian Milton plant: The crucibles do not admit sufficiently good heat transfer, and the ore should be extruded into containers made from alloys and occupy the whole height of the furnace. Further improved heat transfer could be achieved by adding preheated coke to the ore after it has reached red heat. For Swedish conditions the Wiberg-Söderfors method is preferable since it requires half the energy cost and only two man-hours per ton. The tunnel kiln process may be justified in the case of an ore too fine for sintering, where oil, gas, or coke are available at a much cheaper price than electric power, and provided that existing kilns can be utilized.—B. S. E.

PRODUCTION OF STEEL

S.P.T. Expansion: Recent Developments at Templeborough. (Iron and Steel, 1951, vol. 24, Jan., pp. 17–19). This article describes three new developments at the Templeborough Works of Steel, Peech and Tozer. The first is the completion of a new works water supply which includes the largest industrial purification plant in Britain, and has a total pumping capacity of 30 million gal./day with an output of fully treated water of 12 million gal./day. Secondly, the River Don has been diverted to allow better layout of works railway sidings, and thirdly, a new 150,000 tons capacity steel stockyard has been erected.—G. F.

Technical and Metallurgical Progress of the American Steel Industry with Special Reference to Applicability to Austrian Steel Production. F. Leitner. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Oct., pp. 185–191).

Manufacture of Quality Steel in Russia. N. H. Polakowski. (Metal Progress, 1951, vol. 59, Mar., pp. 359–363). This article gives the location of the principal Russian alloy-steel works, and discusses the quality of low-alloy constructional steel, and stainless, heat-resisting, and high-speed steel. It also mentions the conditions of gas-cyaniding, the use of liquid baths, refractory life, the standard of the rolling mills, and production controls. It is concluded that raw materials and refractories are of low grade, and that Russian industrial practice contains little that is novel.—E. T. L.

Instrumentation in Steelmaking. R. A. Lambert. (Instrument Society of America: Metal Progress, 1951, vol. 59, May, pp. 657–659). Papers presented at a conference of the Instrument Society of America supported by other bodies are summarized. They dealt with the instrumentation of open-hearth furnaces using mixed fuels or oxygen, a method of maintaining the viscosity of fuel-oil constant, savings resulting from the use of oxygen in open-hearth furnaces and from the use of instruments and temperature measurements in steelworks. There is a discussion on the best place to sight an optical pyrometer for roof temperatures.—E. T. L.

Model Research: Applications in the Steel Industry. F. Mortimer. (Iron and Steel, 1951, vol. 24, Feb., pp. 39–44, 50). The three main centres of model research in this country in recent years are: (1) The one-fifth scale open-hearth model at Shelton Iron, Steel, and Coal Co.. Ltd., operated by B.I.S.R.A., on which heat-transfer problems were studied; (2) the one-twelfth scale cold-air models at the B.I.S.R.A. Physics Laboratories, for studying mixing conditions; (3) one twenty-fourth scale models with water as the working fluid, at the Research and Development Dept. of The United Steel Companies, Ltd. The value of such model research and the application of the results in the steel industry are discussed, and an indication of further model work now planned is given.—G. F.

Status and Development of the Air-Refining Process. W. Bading. (Stahl und Eisen, 1951, vol. 71, Apr. 12, pp. 373–386). The increase in size and output of open-hearth furnaces and Bessemer converters as the demand for steel has increased is illustrated. The effect of the quality of ore reserves on the most suitable process for refining the resultant pig iron and the problem of enhancing the quality of air-refined steels are discussed. After comparing the production costs of an open-hearth, a basic-Bessemer, and a Duplexing process, each making 600,000 tons of steel per year, the methods by which attempts are being made in many countries to produce low-phosphorus, low-nitrogen steels in the basic-Bessemer converter are described. These include the use of oxygen, steam, carbon dioxide, and ore, and side and oblique blowing. Analyses of steels produced in the various trials are tabulated.—J P.

The Present Position of the Converter Process—Economic Comparison with other Steelmaking Processes. B. Matuschka. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 40–45). A comparison is made between the economic aspects of open-hearth and basic-Bessemer steel production. It is shown that when slag is recovered the ingot costs for the two processes are about equal, provided that the open-hearth plant can work with 50% of scrap: for a works producing one-third basic-Bessemer steel and two-thirds open-hearth steel, the costs are lower than for an entirely open-hearth works, if equal amounts of scrap are available. Costs for blowing stahleisen are higher than those for an open-hearth plant, but in a works combining converters and open-hearth furnaces the total costs are about the same as for entirely open-hearth operation: when oxygen is used for blowing, a steel is obtained whose quality is equivalent to that of open-hearth steel, but at a price 5–10% higher. Steel

made in an induction-heated converter would be as cheap as open-hearth steel, if the charge carried 50% of scrap. The oxygen-blowing process and the induction-heated converter enable a great part of the manganese content of pig iron to be converted into a slag suitable for the preparation of ferromanganese low in phosphorus, and they may thus provide a large part of the ferromanganese needs of Europe.

New Flexible Roof Construction Cuts Furnace Maintenance Costs. (Steel, 1950, vol. 127, Nov. 20, pp. 116–118). A new type of double-hung insulated refractory arch designed and produced by G. P. Reinljes Co., Kansas City, is described. The arch consists of two rows of bricks, the upper being held to the lower by a patented horizontal **S** lock. The upper bricks are suspended from tubing attached to overhead beams or girders ; the bricks cannot become disengaged even though they swing as much as 30° from the horizontal and the lock also prevents disengagement by an upward movement.—A. M. F.

The Design of a New Open Hearth Shop. H. E. Warren, jun. (American Iron and Steel Institute : Industrial Heating 1950, vol. 17, Dec., pp. 2160–2166 ; 1951, vol. 18, Jan., pp. 82–88 ; Feb., pp. 276–280). In the first part the size, location, and preferred construction of facilities which contribute to efficient open-hearth operation are discussed. In the second, the construction of the component parts of some of these facilities, the plant layout, and auxiliary equipment are considered. In the final part, data are given on hot tops, cinder yard and skull crackers, strippers, fuel system, instrumentation, and cooling water supply.—J. A. L.

The Physical Chemistry of Steelmaking. K. L. Fetters. (American Iron and Steel Institute : Industrial Heating, 1951, vol. 18, Jan., pp. 75–80, Feb., pp. 265–274) ; The advances made in slag-metal and physical chemistry research in the last 20 years are reviewed. In the first part, early steel practices and the evolution of physical-chemistry research are considered. In the second part, research projects sponsored by various organisations are discussed.—J. A. L.

Open Hearth Charging Time Cut 55%. L. R. Rissler. (Steel, 1950, vol. 127, Dec. 18, pp. 114–120). A new system of scrap flow in the open-hearth plant of the Armco Steel Co. consists of four special hydraulic hoists to serve three furnaces. The hoist platforms, about 10 ft. × 20 ft. are loaded with one charging bogie at scrapyard level and during the rise to the stage level are rotated through 90° in order to unload in line with the furnace doors. The hoists are designed to lift 45,000 lb. in 30 sec. or 60,000 lb. in 38 sec. The charging time for a furnace is expected to be cut from 3½ to 1½ hr.—A. M. F.

Novel Method of Charging Open-Hearth Furnaces in Use at Armco Plant. C. J. Andreatta. (Blast Furnace and Steel Plant, 1951, vol. 39, Mar., pp. 321–323). In Armco Steel Corporation's new open-hearth plant, containing three 225-ton furnaces, the scrap cars are raised from ground level to the charging floor by hydraulic lifts of 40 tons capacity. This new practice permits faster charging, the two 12-ton charging machines being geared to operate at twice the speed of normal machines. Thermal expansion of the lift structure is overcome by constructing the charging floor on independent supports.—E. J. B.

O.H. Furnace Pressures : Reduction of Errors in Measurement Due to Buoyancy. J. Chapman and G. Lomas. (Iron and Steel, 1951, vol. 24, Jan., pp. 3–6). The authors describe tests carried out under normal furnace working conditions to determine the magnitude, type, and cause of the errors in measurement of open-hearth furnace pressure. With normal uncooled measuring installations, buoyancy variations as great as 0·1 in. W.G. have been observed, and the authors show that this variation can be reduced to about 0·01 in. W.G. by using a very short crown leg and by water-cooling the front-wall leg of the pipeline.—G. F.

Mixer Practice in 1948. M. A. Recht. (Centre de Documentation Sidèrurgique : Circulaire d'Informations Techniques, 1949, vol. 6, Nov.–Dec., pp. 499–506). The functions of a mixer are fourfold : (1) It is required to supply the steelworks with a fairly constant iron quality from the varying casts supplied by the blast-furnaces. In many cases the iron forms layers and the rocking is too gentle, but it has been found that if the iron falls vertically into the middle better mixing is obtained without damage to the bottom. (2) It must maintain as much heat as possible. For this, the capacity should be related to the steelworks' requirements (12 hr. production) rather than to the blast-furnace output, because the iron must not remain there long ; insulation should be good, the magnesite bricks being backed with something like kieselguhr ; there need not be more than two openings, which are weak points ; and gas burners at the ends are advised, but the air should be preheated only as much as is permissible without lining the ducts with bricks since more cold air may be admitted during tapping than elaborate preheaters could make up. (3) It should maintain steady iron temperature ; often mixers are colder on Mondays because of Sunday's accumulated iron, thus causing off-grade steel. (4) Mixers are often used for storage when the steelworks is temporarily out of action ; the author, however, believes that the iron should not be placed in the mixer unless it is going to be used within 12 hr. A table (by Herzog) giving details of 13 German mixers built before 1929, is given.—N. McE.

Metallurgical Oxygen Speeds Foundry Open Hearth Melting. L. L. Whitney. (American Foundryman, 1950, vol. 17, May, pp. 57–59). The use of a high-velocity stream of oxygen in conjunction with fuel oil, for melting down preheated scrap, is reported to have reduced the normal melting time by about 20%. This technique was improved by a dual burner and reducing the forced air. Over a period of three months the following average results were obtained with a 61,000-lb. charge : Charge to tap time 3 hr. 57 min.; fuel-oil consumption 26·6 gal./ton ; oxygen consumption 450 cu. ft./ton. The modification of the practice to suit the conditions imposed by the quality, type, and quantity of scrap is briefly discussed, with some reference to a water-cooled permanent oxygen lance.—E. J. D. S.

Refining a Phosphoric Iron by Oxygen in the Open-Hearth Furnace. G. Husson and P. Bettembourg. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, Feb., pp. 135–139). Tests on charges with 50 and 75% basic-Bessemer iron have given encouraging results and a fuller quantitative study of the process is planned.—A. G.

The Rôle of Alumina in Slags. F. E. Lathe. (Canadian Mining and Metallurgical Bulletin, 1951, vol. 44, Mar., pp. 165–174). The effects of alumina on (*a*) the fusibility of a slag, (*b*) its fluidity and specific gravity, (*c*) the effect of the above factors on metal recovery, (*d*) the influence of composition on the elimination of undesirable impurities from the metal, and (*e*) the rate of slag attack on the refractories used are discussed. In connection with these considerations the following complex oxide systems are examined in detail : $FeO–SiO_2$, $FeO–Al_2O_3$, $CaO–SiO_2$, $Al_2O_3–SiO_2$, $FeO–Al_2O_3–SiO_2$ and $CaO–Al_2O_3–SiO_2$. More complex slags such as $CaO–FeO–Al_2O_3–SiO_2$, $CaO–FeO–Al_2O_3–SiO_2–MgO$, and $CaO–FeO–Al_2O_3–SiO_2–MgO–MnO–P_2O_5$ are also studied.—T. E. D.

Faster Cooling Key to Jacquet Continuous Casting Method. (Steel, 1950, vol. 127, Dec. 4, pp. 108–113). This article describes the Jacquet method of continuous casting of steel. The primary difference from other methods is in the use of multiple horizontal moulds to increase the cooling surface and permit the casting of steel without the necessity of reheating the charge and without exceeding the maximum stripping speed.—A. M. F.

Interest in Continuous Steel Casting Gains Momentum. (Steel, 1950, vol. 127, Dec. 25, pp. 68–72). This article summarizes the technical session of the eighth annual conference of the Electric Furnace Committee, American Institute of Mining and Metallurgy, when the subject of continuous casting was discussed. A description of the plant of Babcock and Wilcox at Beaver falls is given. A mould is now being constructed for casting a slab of 100 sq. in. for rolling to a width of 26 in. on a continuous strip mill.—A. M. F.

Progress in Electric Steelmaking. S. W. Poole. (Metal Progress, 1951, vol. 59, Jan., pp. 93, 102–112). This is an account of the papers of the December, 1950, meeting of the Electric Furnace Steel Committee of the American Institute of Mining and Metallurgical Engineers. (Abstracts of these papers will appear later in the *Journal*).—E. T. L.

The Use of Oxygen in the Arc Furnace—Experiments Carried out in February and May 1948 in a 10-Ton Furnace. M. Delbey. (Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1949, vol. 6, Nov.–Dec., pp. 513–522). Full details are given of a series of experiments in using oxygen to remove carbon from steels in a 10-ton arc furnace. The increased proportion of oxygen required when the carbon was under 0·1% agreed with theory. The enhanced speed of the process and decreased consumption of

other materials made it economical. When producing steels with 5 or 6% chromium the use of oxygen obviates the carrying of a heavy slag that slows down the oxidation, corrodes the lining, absorbs the chromium, and is irrecoverable owing to its large bulk; the method was to oxidize with oxygen, allowing the chromium to enter the slag, and then to reduce this light slag with calcium silicide, thus recovering 60% of the original chromium. However, owing to the exacting conditions only 40% of the runs attempted were successful. The process would have been more economical if less effort had been expended in recovering chromium.—N. MCE.

Single-Slag Melting in Acid Electric Furnaces. H. Biers. (Instituto del Hierro y del Acero, 1951, vol. 4, Jan.–Mar., pp. 39–51). [In Spanish]. The author briefly describes a recommended process for making 2½ tons of steel for moulds in a small acid electric furnace. The analysis was C 0·20–0·25%, Mn 0·60–0·70%, Si 0·30–0·50%, P 0·05% max., and S 0·06% max.—R. S.

Single-Slag Melting in Basic Electric Furnaces (Steel for Moulds). H. Biers. (Instituto del Hierro y del Acero, 1950, vol. 3, Oct.–Dec., pp. 288–295). [In Spanish]. General precautions when charging electric furnaces are given. Methods of working the oxidizing and reducing slags, tapping, and ladle additions for final deoxidation are described. Details are given of slag-making materials, and calculation and control of charges to make steel with C 0·25%, Mn 0·67%, Si 0·40%, S 0·035%, and P 0·02%.—R. S.

FOUNDRY PRACTICE

Designs of Casting. F. B. H. Van Bergen. (Metalen, 1951, vol. 6, Apr., pp. 124–132). [In Dutch]. The author discusses practical points connected with improvement of quality of castings and lowering of cost. These include finish, design, and economy of pattern form.—R. S.

Construction of a Casting. C. N. Van Der Velden. (Metalen, 1951, vol. 6, Jan., pp. 17–19). [In Dutch]. The author deals very generally with methods of avoiding defects in the preparation of castings. Importance of good design and the issue of processing instructions is stressed.—R. S.

Structural Production Organization in the Foundry. P. Rohrhirsch. (Neue Giesserei, 1950, vol. 37, Dec. 28, pp. 588–592). In considering the best layout of the foundry and the designs of individual workplaces the author stresses the importance of the human factor. [An English translation of this paper is given in the Foundry Trade Journal, 1951, vol. 90, Mar. 22, pp. 315–319].

Losses in Compressed Air Plants in Foundries. F. Imberger. (Giesserei, 1951, vol. 38, Jan. 11, pp. 2–4). Losses are analysed into those caused by leaks, pressure drop in transmission lines, and by the use of unsuitable compressors. On the whole, a plant consisting of several small compressors is more adaptable than a single large unit, but the latter is more efficient and the initial outlay is smaller.—J. G. W.

Burning-In the Cupola Bed. B. P. Mulcahy. (American Foundryman, 1950, vol. 18, July, pp. 42–45). The principal factors determining the cupola coke-bed height are enumerated and their possible influences on operation are indicated. Recommendations are made to remove the element of uncertainty in this part of cupola practice.—E. J. D. S.

Charging Steel Swarf into the Cupola. (Fonderie, 1951, Mar., pp. 2406–2408). The chemical composition, dimensions, and physical state of steel swarf of various types are discussed. The introduction of steel to the charge necessitates extra coke additions between charges and causes increasing losses of manganese and silicon by oxidation.—R. S.

Arrangements for Charging Small Cupolas. (Fonderie, 1951, Feb., pp. 2363–2365). A little-known method of charging small cupolas by means of a pivot angle-bracket crane is described.—R. S.

Foundry Scrap. (Fonderie, 1951, Jan., pp. 2333–2334). In view of the variation in foundry scrap, some general indications are given to enable homogeneous charges to be made. Analyses of various classes of scrap are given. The average thickness of the scrap should be suitable for the average thickness of the castings to be made.—R. S.

Oxygen-Enriched Blast in the Operation of Cupolas. K. F. Mewes. (Neue Giesserei, 1950, vol. 37, Nov. 2, pp. 491–492). Interest in oxygen-enriched blast for cupola operation has been reawakened. Conditions are economically less favourable than for steelmaking on account of the smaller oxygen consumption—too small for the cheap generation of oxygen, too large for the use of oxygen bottles. On the basis of tests with an experimental furnace 50 cm. inside dia. the author concludes that although an 8% oxygen addition to the blast led to either a 40% increase in the melting capacity or an increase of 40° C. in the pouring temperature, these results cannot be applied in practice for economic reasons. He recommends, however, the use of oxygen for short period 'injections' to correct faults in the melting process, *e.g.*, the 'cold-iron periods.' For this purpose a battery of bottles with regulating valves should be used. Results of five monthly trials with two furnaces are given, in which 2-min. and 3-min. injections were used to raise the temperature quickly.—J. G. W.

The Use of Oxygen in Cupolas. J. Natkaniec. (Hutnik, 1951, vol. 18, Apr., pp. 158–160). [In Polish]. The use of oxygen-enriched blast for cupolas is briefly discussed, and the results of experiments in the U.S.S.R. and the U.S.A. are considered.—V. G.

Annealing of Malleable Iron Castings in Electric Furnaces. (Industrial Heating, 1951, vol. 18, Jan., pp. 46–48). This article describes the installations at the National Malleable and Steel Casting Co., Cleveland, Ohio, of five electric annealing furnaces. Three of them are high-temperature annealing furnaces, rated at 390 kW., maintaining a temperature of 1800° F. The other two are low-temperature tempering furnaces rated at 230 kW., with a maximum temperature of 1300° F. The control and operation of these furnaces are also briefly described.—J. A. L.

Annealing of Whiteheart Malleable Cast Iron. G. Joly. (Metaux–Corrosion–Industries, 1951, vol. 26, Jan., pp. 3–9). In the manufacture of white-heart malleable castings it is necessary to soften the surface of the castings as they are otherwise too hard and brittle for machining. The physical principles of this annealing process are examined. The castings are covered with an oxidizing cement which decarburizes the surface at high temperatures, or the deoxidation is achieved by passing a mixture of carbon monoxide and dioxide over the hot metal. The softening involves the oxidation of the carbon in the surface; the diffusion of carbon from the interior to the decarburized surface; and the solution of the hard, free cementite. At a later stage, when the free cementite is dissolved, graphitization also occurs in which the austenite attempts to dissolve the precipitated graphite. The velocity of diffusion of carbon is the most important factor of the process, and this velocity depends upon (*a*) speed of solution of cementite, and (*b*) graphitization. The factors influencing (*a*) are then discussed under the headings of annealing temperature, chemical composition, thickness of specimens, and casting temperature, while the factors determing (*b*) are examined in terms of the annealing temperature, the silica content, and the sulphur/manganese ratio.—P. F.

Desulphurizing Gray Cast Iron with Magnesium. J. E. Rehder. (American Foundryman, 1950, vol. 18, Sept., pp. 43–49). This investigation was to determine the desulphurizing action of ladle additions of magnesium or magnesium alloys, apart from the formation of nodular graphite. Some of the conclusions are: Desulphurization is rapid and consistent with additions of magnesium alloys to the ladle, and if the final sulphur content is above 0·03% it may be achieved without exceeding a residual magnesium content of 0·02%. Irons containing 0·33% sulphur can be desulphurized consistently with magnesium, whilst the carbon and silicon contents of the iron do not appear to have much effect on the efficiency within the limits of 2·5 to 3·6% carbon and 1·0 to 2·8% silicon. The sulphur content must be decreased to about 0·02 to 0·03% before a residual magnesium content of 0·2% is exceeded, at which point the quantity of nodular graphite increases.—E. J. D. S.

Contribution to the Treatment of Cast Iron with Magnesium Hardeners in the Ladle. A. Wittmoser. (Neue Giesserei, 1950, vol. 37, Nov. 30, pp. 533–540). The author sets out the factors which have to be considered when choosing the suitable magnesium hardeners. He recommends Mg–Cu–Si–Fe and Mg–Ni–Si–Fe hardeners as least difficult to introduce. With the aid of published data and of experiments he tried to elucidate the efficiency of the reaction with reference to the temperature and time factors. The results of the experiments were not entirely satisfactory owing to differences between the assessments by different observers.—J. G. W.

Further Results of Belgian Nodular Cast Iron Research. A. De Sy. (American Foundryman, 1950, vol. 17, May,

pp. 75–83). A survey of conditions favourable to the formation of nodular cast iron, and the application of an empirical formula for calculating the quantity of magnesium required in magnesium-treated irons is presented. The results of experiments to determine the functions of elements other than magnesium or cerium are reported. Strontium, calcium, and lithium were tried, with limited success. Experiments using various magnesium alloys are also briefly reported.—E. J. D. S.

Nodular Iron—A Bibliography. F. R. Morral. (American Foundryman, 1950, vol. 18, July, pp. 61–74). There are 137 references, together with several micrographs and electron-micrographs of the structure of graphitic nodules.—E. J. D. S.

Some Experiences in Producing Ductile Iron. E. M. State and B. L. Stott. (Foundry, 1950, vol. 78, July, pp. 80–83). The gradual change-over from the production of grey-iron castings to the production of magnesium-containing castings is discussed. The range of products is illustrated.—E. J. D. S.

Producing Ductile Cast Iron : Some Foundry Experiences. N. Croft. (Institute of British Foundrymen : Iron and Steel, 1951, vol. 24, Feb., pp. 45–50). The author discusses the practical aspects of the production of nodular cast iron by magnesium treatment and gives examples of its present industrial applications. He emphasizes that its commercial development requires close control of all the production processes, and that much work remains to be done before the material can be used to the best advantage. A consistent material can be produced satisfactorily, and typical values of its mechanical properties are given.—G. F.

Irons with Spheroidal Graphite. J. B. Guillaumin. (Métaux et Industries, 1950, No. 1, pp. 11–13). An American method for making malleable cast iron with nodular graphite by a small addition of magnesium alloy is recommended. Sulphur and phosphorus are deleterious. In the as-cast condition the maximum stress is increased by 120% and the resistance to shock by 300%. The Young's Modulus can reach 11,000 tons/sq. in. After a heat-treatment of only 4 hr. an iron of high ductility (12–20% elongation), though lower strength, can be obtained.—N. McE.

Comparative Growth of Gray Iron *vs.* Nodular Iron when Cyclically Heated to 1650° F. T. E. Eagan. (Foundry, 1950, vol. 78, Dec., pp. 96–99, 203–204). Grey and nodular iron specimens subject to an identical series of annealing cycles at 1650° F. provided evidence that nodular iron is much less prone to growth than grey iron. Growth of these irons is due to oxide penetration and graphitization, the former process being helped by graphite in the flake form. The quantities and functions of carbide stabilizers for grey irons and their influence on the growth behaviour are discussed.—E. J. D. S.

Dies for a Malleable Production Foundry. K. L. Sanders. (American Foundryman, 1950, vol. 18, Aug., pp. 24–26). Four types of die for straightening malleable castings to provide dimensional accuracy are described.—E. J. D. S.

Malleable Iron Annealability. M. Tilley. (American Foundryman, 1950, vol. 17, May, pp. 88–89). Malleable iron casting troubles such as mis-runs, shrinks, hot tears, and annealing rejections, could be reduced if oxidizing conditions during melting were more closely controlled. Metal inadvertently over-oxidized may be restored by making a large addition of ferrosilicon.—E. J. D. S.

Contribution to the Knowledge of Ore for Malleablizing Iron. F. Roll. (Giesserei, 1951, vol. 38, Jan. 11, pp. 4–8). The quality of the ore in which castings are packed for making them malleable and the reactions occurring are discussed. The composition may alter appreciably during the annealing process, *e.g.*, through taking up sulphur.—J. G. W.

The Constituents of Moulding Sands. M. Guédras. (Métallurgie, 1951, vol. 83, Jan., pp. 9–13). The geological formation and classification of sands are described. The properties of silica and alumina are listed and a brief note on permeability is added.—R. S.

A New Mixing Principle for Sand Preparation. H. List. (Neue Giesserei, 1950, vol. 37, Apr. 6, pp. 140–141). The "Ko-Mischer" made by Buss A.G., of Basle/Pratteln, Switzerland, comprises a shaft carrying an interrupted archimedean screw working in a trough with internal baffles. By giving the shaft a combined rotary and reciprocating motion, the baffles can pass through the gaps in the screw, carrying some of the sand from one compartment to the next at each passage. The largest machine mixes 10 cu. m./hr., and it is claimed that the mixing time is reduced to between $\frac{1}{20}$ and $\frac{1}{30}$ of the usual time.—H. R. M.

Nature of Moulding Sand and New Methods of Testing Its Properties. W. Reitmeister. (Neue Giesserei, 1950, vol. 37, Dec. 28, pp. 585–588). As a result of further investigations the author amplifies the interpretation of the relation between 'grain volume' and moisture content, which he described in an earlier paper (*see* Journ. I. and S.I., 1951, vol. 169, Sept., p. 59). It appears that for some sands the grain volume and gas permeability both change with moisture content and these sands possess high and rapidly rising strengths in the loosening range ; for other sands, which possess little strength in this range, the above two quantities change in the opposite sense.—J. G. W.

Silica Sands—Sieve Analyses. A. I. Krynitsky and F. W. Raring. (American Foundryman, 1950, vol. 18, Aug., pp. 40–43). A study of sieve analyses of silica sand was undertaken to determine whether the type of sieve shaker used had any significant effect on the size analysis, and its reproducibility, and the precision of the American Foundrymen's Society fineness test for foundry sands. It was found that vibratory and rotary types of shaker yield approximately the same results on a given sample with the same set of sieves. For nine samples, the average fineness number was 70·6 for the first type and 70·4 for the second.—E. J. D. S.

Sand Control Should Include Mixer Operator Training. E. W. Fry. (American Foundryman, 1950, vol. 18, Nov., pp. 56–58). Experiments in a grey-iron jobbing foundry have led to the adoption of two all-purpose sands which resulted in the simplification of mixing and sand distribution. The first was an all-purpose base sand of silica containing no clay, 16·4% fines, and an A.F.S. fineness of 65·0. The second all-purpose system sand contained 7% clay, 4·5% fines, and an A.F.S. fineness of 62·0. The size distribution of the system sand differed from the base sand because of the inclusion of core sand in the shake-out, although for heavy cores the mixture contained half base sand and half coarse sand. Sieve analyses are given.—E. J. D. S.

Mechanize Sand Conditioning and Distribution System at Ohio State. J. W. Anibal. (American Foundryman, 1950, vol. 17, May, pp. 85–86). The modernization and layout of the foundry laboratory at the Ohio State University is briefly described.—E. J. D. S.

Use of Belgian Moulding Sand in the Steel Foundry. K. Roesch. (Neue Giesserie, 1950, vol. 37, Dec. 28, pp. 581–584). The properties of Belgian moulding sands are described and compared with those of typical German ones.—J. G. W.

Mineral Perlite—Foundry Uses. E. D. Boyle. (American Foundryman, 1950, vol. 18, July, pp. 25–26). Investigations into the use of sand additives for improving the insulating properties of moulding sands and cores indicate that the mineral perlite reduces the speed of solidification of the casting and eliminates casting defects arising from expansion. The application of this mineral in the production of ferrous and non-ferrous castings is described.—E. J. D. S.

The Surface of Green Sand Castings. P. Nicolas. (Fonderie, 1951, Jan., pp. 2331–2333). The finish of green-sand castings depends on the original nature of the new pit sand, method of packing, use of insulating material, and conditions of casting.—R. S.

J.I. Case Co. Modernizes Coremaking Facilities. (Foundry, 1950, vol. 78, Nov., pp. 212–214). A mechanized core shop at this firm is very briefly described. With the replacement of manual handling a saving of 25% was effected. Core rejects and breakage were reduced by more than 25% and core quality was improved considerably.—E. J. D. S.

Mechanical Core-Making in the N.V. De Globe Foundry at Tegelen. (Metalen, 1951, vol. 6, Jan., pp. 23–26). [In Dutch]. Calculation of the energy (in kgm.) required to make a complete core box shows the considerable amount of energy used in handling the empty and full moulds. The lay-out of the De Globe foundry illustrates the labour-saving technique of using trays on a roller-conveyor. In this way, the mixer always has empty boxes at hand and can place his full boxes directly on the conveyor.—R. S.

Wood Grain and Its Influence on the Quality of Glued Joints in Foundry Patterns. A. H. F. Goederitz. (Neue Giesserei, 1950, vol. 37, Nov. 16, pp. 509–515). From experiments with glued joints it follows that the dovetail joint is in every respect mechanically weaker than any sort of straight serrated joint.—J. G. W.

Wood-Working Machines for Pattern Making. (Neue Giesserei, 1950, vol. 37, Apr. 20, pp. 161–162). A range of machines made by a German firm is briefly described and illustrated. They include precision planing machines for widths up to 1300 mm., milling machines either of the normal type or with an inclinable cutter spindle, and wet grinding machines for planer blades up to 1700 mm. long.—H. R. M.

Application of Atmospheric Feeding Heads in Steel Casting. T. Budinszky. (Kohászati Lapok, 1951, vol. 6, Jan.; Öntöde, 1951, vol. 2, Jan. pp. 4–12). [In Hungarian]. The author has developed a method of introducing air at atmospheric pressure underneath the first solidified outer crust of the feeder head during the solidification of steel castings. The results obtained are very satisfactory. Its advantages are: Better utilization of the liquid steel; fewer shrinkage cavities; reduced cleaning and machining costs; easier removal of feeder heads; drastic reduction in the percentage of rejects; and greater density of the castings. A disadvantage is that dirt in the feeder head is also pressed into the casting; this has to be taken into consideration in the design of the feeder heads.—E. G.

Principles of Gating. W. H. Johnson, W. O. Baker, and W. S. Pellini. (Foundry, 1950, vol. 78, July, pp. 70–74, 204–208). Experimental observations, using a photographic technique, and an analysis of the flow of molten steel into a mould through multiple openings in both horizontal and vertical planes are presented. Actual flow conditions are said to change continually during pouring. The initial entry of metal into a gating system approaches free fall but, as the system fills, a ferrostatic back pressure is developed and the action approximates that of a pressurized system. It was shown that uniform flow could be obtained by: (1) Elimination of pronounced momentum-pressure effects by the use of enlargements; and (2) the control of momentum-pressure effects to aid proper feeding by having sharp angles, constrictions, or increased flow distance.—E. J. D. S.

Steel Casting in South Africa—Feeding Techniques. H. G. Goyns. (American Foundryman, 1950, vol. 18, Nov., pp. 50–55). The production, in South Africa, of certain classes of steel casting and the handicaps and scope of the steel-foundry industry in that country are reviewed. Despite the lack of modern techniques the yield of castings is surprisingly high, *e.g.*, buffer castings have been produced with a 70% yield. Feeding methods used are also discussed.—E. J. D. S.

Bandsawing in Foundries. G. H. Sheppard. (Canadian Metals, 1951, vol. 14, Mar., pp. 18–21, 24, 45–46). Bandsawing of rough ferrous and non-ferrous castings is described and discussed, saws with infinitely variable band speeds between 40 and 1500 ft./min. being now available. Data and details are presented concerning production rates, saw life, cutting techniques, and types of saw. Requirements of surface finish and tolerance are considered, also conditions of economic operation.—E. C.

Continuous Filing as Applied to Castings. H. J. Chamberland. (American Foundryman, 1950, vol. 18, Dec., pp. 37–40). The advantages of band-filing as a production tool are illustrated and discussed. This process is reported to be four times as fast as reciprocal machine files.—E. J. D. S.

Casting Steel Crankshafts. E. Bremer. (Foundry, 1951, vol. 79, Mar., pp. 84–87, 245). The layout and operation of a foundry making crankshafts in slab core moulds with cavities for producing four castings attached to a simple sprue, is described.—E. J. D. S.

Metallurgy of Iron Base Rolls. F. E. Sutherland. (American Foundryman, 1950, vol. 18, Aug., pp. 46–51). The melting practice for casting different grades of iron roll is discussed. The depths of chill are reported to be controlled to within ± 0·025 in. The capacity of the air furnace (25 tons), fired with bituminous coal, is an important feature of the melting procedure and control. The functions of the following elements in making iron rolls are described: Silicon, manganese, sulphur, phosphorus, molybdenum, nickel, and chromium.—E. J. D. S.

Snap Flask Moulding. (Fonderie, 1951, Mar., pp. 2392–2405). Equipment for snap-moulding is described. The making of various types of snap mould, marking devices for frames, match-plates, pressure boards, and side plates is discussed. Some precautions to be taken in snap-moulding are mentioned.—R. S.

Casting Design for Economical Moulding. C. T. Marek. (Foundry, 1950, vol. 78, Nov., pp. 88–93, 248–252). The influence of casting design on the method of production is discussed, the article consisting of a chapter from 'Fundamentals in the Production and Design of Castings' by the same author.—E. J. D. S.

Centrifugal Casting for Critical Components. H. Cooper. (Machine Design, 1950, vol. 22, Nov., pp. 131–132). Centrifugal casting may be divided into three broad categories—centrifuging, centrifugal pouring, and true centrifugal castings; these are defined. The first important use of true centrifugal casting with metal moulds was stimulated by requirements for jet-engine rings. The advantages of the method over static casting are shown by photographs of macrostructure. The Cooper Alloy Foundry Co. has been pouring stainless steel castings centrifugally in permanent metal moulds since December, 1947, and the author outlines the following factors: High casting quality, increased ductility, lower unit costs, applications, and design considerations.—E. C. S.

French Foundry Casts Chain Centrifugally. R. Ronceray. (American Foundryman, 1950, vol. 18, Sept., pp. 41–42). A centrifugal casting process is described in which almost 11 ft. of steel chain are cast in one mould made entirely of cores. As cast, the chain appears as a cluster of short vertical lengths around a central sprue and weighs about 13·25 lb. With sprue and gates the casting weighs 22 lb. Cleaning of the precision cast cluster consists of separating the gates from the links with a cutting disc.—E. J. D. S.

Pressure Casting, Quality and Price of Tools. R. Grunberg. (Métallurgie, 1951, vol. 83, Feb., pp. 93–95, 105; Mar., pp. 157–159). Standard moulds for pressure casting are described. The properties required in steel for pressure-casting moulds are listed. Factors affecting the life and wearing properties and the cost of moulds are discussed.—E. S.

The Precision Casting Process. W. H. Sulzer. (Neue Giesserei, 1950, vol. 37, Dec. 14, pp. 557–565). This is a survey of precision investment casting, in which the procedures involved are described with details of moulding materials and the drying and baking methods.—J. G. W.

Tolerances for Investment Castings. T. F. Frangos. (Machine Design, 1950, vol. 22, Oct., pp. 107–108). A casting of a compact shape will have low dimensional variation, due to the small length/thickness and length/width ratios. The effect of tolerances on costs is shown with an arbitrary casting-dimension frequency distribution. If ± 0·003-in. limits are required, then 22% of the castings are rejects. If ± 0·005-in. limits are acceptable, then there are only 8% rejects. The lowest cost is reached when ± 0·010-in. limits are permissible as then there are no rejects.—E. C. S.

The Fields of Utility of Investment Castings. R. L. Wood and D. Von Ludwig. (Mechanical Engineering, 1951, vol. 73, Mar., pp. 191–197). The problems arising daily when using the investment process are discussed. The groups of castings dealt with are: (*a*) Castings which cannot be made by any other method; (*b*) castings previously made by other processes; (*c*) castings serving as a trial material during design evolution; (*d*) castings which, although investment cast, represent an uneconomic application of the process owing to incorrect design or material selection.—D. H.

Investment Casting in the Design of Machine Parts. V. di Sambuy. (Rivista di Meccanica, 1950, vol. 1, Sept. 1, pp. 19–21). [In Italian]. A brief description is given of investment-casting technique. The accuracy obtainable and the advantages of the method for complex castings are described. The range of type and size of parts, which can be economically produced by investment casting are discussed. A comprehensive bibliography is given.—M. D. J. B.

A Triple-Purpose Foundry: Mechanized, Semi-Mechanized, and Jobbing. (Iron and Steel, 1950, vol. 23, June, pp. 289–294). The Foundry Division of Beans Industries, Ltd., has three distinct types of production on the one site: (*a*) Mass production on mechanized plant; and (*b*) medium repetition on moulding machines and roller conveyors; and (*c*) jobbing work by floor moulding. The layout and operation of the mechanized foundry are described in detail, and brief descriptions of the medium-repetition cylinder-block foundry and the jobbing foundry are also given.—G. F.

Repetition Castings: Successful Mechanization at Triplex Foundry. (Iron and Steel, 1951, vol. 24, Mar., pp. 75–82). The foundry of Triplex Foundry, Ltd., Great Bridge, has recently been mechanized. The general layout of the new

foundry and its operation are described, and full details of the various items comprising the sand conveyor systems and the moulding machines are given.—G. F.

400-Year-Old Belgian Foundry. R. Doat. (American Foundryman, 1950, vol. 18, Sept., pp. 57–59). A brief history of the type and quality of casting produced by the Vennes foundry, founded in 1548 at Liége, is given. A remarkable feature of some early products (cooking utensils) was their grey-iron quality produced by making the iron from ore generally containing zinc.—E. J. D. S.

Opening of the New Mechanized Iron Foundry of Rademakers N.V. at Klazienaveen. (Metalen, 1951, vol. 6, Mar., pp. 93–96). [In Dutch]. The layout of this foundry is illustrated and the core-making, transport of sand, melting, casting, and the cleaning of castings are briefly described.—R. S.

Modern Centrifugal Casting Foundry. F. Grosser. (Neue Giesserei, 1950, vol. 37, Nov. 30, pp. 540–543). The new foundry at the Buderus ironworks in Wetzlar is described. Figures throwing some light on the capacity are given, and the economic aspects are considered.—J. G. W.

Producing Textile Machinery Castings. P. Dwyer. (Foundry, 1950, vol. 78, July, pp. 84–87, 211–212). The early history and development of the Whitin Machine Works, Mass., are outlined.—E. J. D. S.

A Compressor Foundry. (Foundry Trade Journal, 1951, vol. 90, Mar. 1, pp. 223–226). The Broom and Wade foundry produces about 10,000 castings a week, some of which, *e.g.*, cylinders, cylinder heads, and valves, have to withstand a water pressure of 120 lb./sq. in. The closely controlled metal is melted in two 3½-ton/hr. and one 7-ton/hr. cupola, one grade only being melted, ladle innoculants being used to counteract size and weight ranges. Virtually all moulds, both light and heavy, are machine made, the patterns used being made of iron or aluminium. The highly mechanized core shop is fitted with core-blowing machines, and the cores are dried by infra-red rays. Water sprays, located at strategic points, efficiently keep down the dust.—J. E. W.

Technical Control Emphasised at a Rochester Foundry. (Foundry Trade Journal, 1951, vol. 90, Mar. 29, pp. 335–340). Kent Alloys Ltd. orginally was a service foundry for Short Bros. In its subsequent development it has changed hands, and an iron foundry, die-casting shops, and ancillary sections have been added. Only high-quality castings are made, quality being maintained by modern technical control and constant maintenance of moulding equipment. Devices are described which enable a large percentage of female operatives to be employed in the moulding shop.—J. E. W.

G. & J. Weir's Foundry and Heat Treatment Facilities. (Foundry Trade Journal, 1951, vol. 90, Mar. 29, pp. 333–334, 343). Holm Foundry, Cathcart, is a jobbing foundry producing castings required for the manufactures of G. & J. Weir, Ltd., and repetition castings suitable for mass production are made at the Argus Foundry, Thornlie Bank. The melting, sand preparation, mould drying, non-ferrous section, and heat-treatment departments are described. A feature of the latter is furnaces 22 in. in dia. and 108 in. deep, operating at 1000° C., the depth divided into three zones, each controlled by a step transformer allowing a variation of current in each zone. These furnaces are used for heat-treating shafts varying in diameter along their length.—J. E. W.

North British Steel Foundry. (Foundry Trade Journal, 1951, vol. 90, Mar. 8, pp. 249–256). Locomotive and tramway wheel centres, gear wheels and blanks, brake shoes, colliery castings, cast-steel crankshafts, and pipes and pipe flanges, are made by the 350 employees at the above foundry. The cupola/side-blown-converter process serves the foundry, low and medium carbon steels, as well as alloy steels being made. A double and sometimes a triple ladle desulphurizing treatment, with soda ash successfully reduces the sulphur from 0·10 to 0·04% or even to 0·02–0·03%. Refractory losses in the converter are low, averaging 19 lb./ton of metal melted. The ladle to ladle time is 20 min. actual blowing time varying from 8 to 13 min. depending upon the weight of the charge. The recently reorganized cleaning and dressing shops are equipped with hydroblast. Normalizing of the castings is done in a Wellman-Smith, double bogie, coal-fired furnace, which employs an automatic stoker giving a positive air/fuel ratio control on a pre-set thermostatically regulated cycle.—J. E. W.

International Harvester Opens $1,200,000 Research Foundry. (American Foundryman, 1950, vol. 18, Sept., pp. 50–53). The scope and future plans of this new research foundry are broadly discussed.—E. J. D. S.

Solidification of Steel from Sand and Chill Walls. H. F. Bishop, F. A. Brandt, and W. S. Pellini. (American Foundrymen's Society, 1951, Preprint No. 21). Thermal studies of solidification of steel from chill and sand walls have shown that solidification proceeds in wave-like fashion by the travel of 'start' and 'end of freeze' waves. The thermal characteristics of the mould walls determine the rate and mode of travel of these waves. In the case of the chill walls which remove heat at a high rate, the two waves travel in conjunction thus creating a band of freezing which proceeds to completion through isothermal liquid. In the case of sand walls which heat at relatively low rates the process is distinctly different in that the 'start of freeze wave' completes its travel through isothermal liquid separately, creating a semi-solid condition which extends through the entire casting. The effects of wall thickness and superheat of the metal have been shown to modify the timing and rate of progression of the freezing waves.—P. C. P.

Rejects in the Grey Cast-Iron Foundry with Particular Reference to the Question of Pig Iron. E. Feil. (Giesserei, 1951, vol. 38, Jan. 25, pp. 29–33). The author examines the mixing of the cupola charge with particular reference to the pig addition, in relation to rejects. He concludes that frequently the pig iron is made responsible for casting faults which in fact are due to other causes. Particular attention should be paid to the degree of carbon saturation in the iron. Examples are given which support the idea that structure may be inherited. The author recommends classification of the pig iron with reference to the amount of combined carbon. The methods of testing moulding sand adopted by the author are described, also with reference to possible causes of casting failures.—J. G. W.

Definition and Classification of Foundry Defects of Metallurgical Origin. A. Portevin. (Fonderie, 1951, Feb., pp. 2345–2358). The author classifies foundry defects of metallurgical origin as follows: (*a*) Chemical (liquation and segregation, gases); and (*b*) physical (variations in volume and fluidity due to cooling and solidification). The nature of these defects is described in relation to many variables in foundry techniques. The association between the various mechanisms of defect formation is noted. Examples of different interpretations of the same defect are discussed. Reference is made to the literature on this subject.—R. S.

What's Wrong with Castings? J. B. Caine. (Foundry, 1951, vol. 79, June, pp. 106–108, 267–271). The relative importance of different kinds of casting defect as stress raisers is illustrated and these defects are compared with those occurring in fabricated components. The importance of stress concentration from the point of view of metal composition and defect is emphasized, and photoelastic and lacquer methods of showing this are introduced.—E. J. D. S.

Establish Foundry Controls through Laboratory Services. (American Foundryman, 1950, vol. 18, July, pp. 58–60). Examples are given of the variety of services provided by large commercial laboratories to facilitate and improve foundry practice in those plants not equipped with their own control laboratories.—E. J. D. S.

Fume Control—Electric Melting Furnaces. J. M. Kane and R. V. Sloan. (American Foundryman, 1950, vol. 18, Nov., pp. 33–35). From dust-removal experiments on several electric steel-melting furnaces, the amount of dust to be expected was shown to be of the order of 5 to 8 lb./hr./ton of metal melted. This amount can be reduced by about 75% with wet-dust-collection equipment, and if local exhaust ventilation methods are used on a furnace, total exhaust volumes can be reduced, thereby limiting the cost of equipment. The particle-size counts on the dusts (iron oxide and silica) collected in the experiments showed 95% less than 0·5 micron.—E. J. D. S.

Modern Training in the Foundry. D. J. da Silva and J. J. Verzül. (Jernindustri, 1950, vol. 31, Aug., pp. 134–140). [In Norwegian]. The training of apprentices in Dutch foundries is described in detail.—B. S. E.

The Camera—A Useful Foundry Tool. B. Melnitsky. (Foundry, 1950, vol. 78, Nov., pp. 108–113, 206). A non-technical description is given of the use of the camera and other photographic apparatus in materials stocktaking, training in foundry safety, foundry production methods, motion study, and metallurgical control.—E. J. D. S.

Cost Assessment when Mechanizing Iron Foundries. O. Warne. (Teknisk Tidskrift, 1950, vol. 80, Apr. 22, pp. 353–358). [In Swedish]. Mechanization of the actual moulding process is considered to be the first aim. The transport system should then be mechanized.—B. S. E.

A.F.S. Foundry Glossary Defines Useful Foundry Terms. (American Foundryman, 1950, vol. 18, July, pp. 40–41, 92–94; Aug., pp. 54, 80, 81, 85–91; Sept., pp. 62–64, 82, 83, 85–91). A glossary of foundry terms, with definitions, is presented.

HEATING FURNACES AND SOAKING PITS

Electric Resistance Heating of Steel Billets. B. Andersson. (Teknisk Tidskrift, 1949, vol. 79, Jan. 8, pp. 17–27). [In Swedish]. The shortage of fuel in Sweden necessitated the development of resistance heating, the technique of which and costs are reported. The disadvantages of this method in comparison to furnace or high-frequency heating include: Uniform cross-section along the blank is required, the material must be squarely cut and free from rust, and the method is less suitable for reheating previously partly heated materials.—B. S. E.

Electrical Resistance Furnace as a Means of Improving Quality. H. Friedrich. (Metall, 1951, vol. 5, Jan., pp. 14–16). Electrical resistance furnaces are classified, described, and illustrated, and applications in the metal and other industries are stated.—J. G. W.

Solution of Certain Unsteady Heat Flow Problems by Relaxation Methods. A. Gilmour. (British Journal of Applied Physics, 1951, vol. 2, July, pp. 199–204). The use of relaxation methods to solve unsteady heat-flow problems in which only one space dimension is involved is demonstrated by application to problems of heat transfer through the walls of highly insulated containers used for transporting frozen produce which requires low storage temperatures. In the problems considered various boundary conditions are encountered and these are readily dealt with by the relaxation technique.

The Reduction of Heat Radiation from Furnace Walls by Means of Aluminium Paints. K. Magnusson and L. Svensson. (Teknisk Tidskrift, 1950, vol. 80, June 17, pp. 581–582). [In Swedish]. For maximum efficiency in reducing radiation losses a fast-drying varnish containing flaky aluminium powder is recommended. Recommendations for a suitable varnish are made.—B. S. E.

High Speed Heating of Steel. M. H. Mawhinney. (Industrial Heating, 1951, vol. 18, Jan., pp. 40–44, 172–176). Several continuous heating furnaces are considered in which the rate of heating exceeds 100 lb. of material per hour per sq. ft. of hearth area. The purpose is to prove the continued relationship between heat transfer and heating rate, already established for heating rates below 100 lb./hr./sq. ft., and to demonstrate the use of the data in particular cases.—J. A. L.

Preventing Fuel Explosions in Gas- and Oil-fired Industrial Furnaces. J. B. Smith. (American Gas Association: Industrial Heating, 1950, vol. 17, Oct., pp. 1718–1719, 1862; Nov., pp. 1950–1954). A description is given of causes of, and preventive measures for, explosions in oil-fired furnaces. Recommended safety practices for direct internally and direct externally fired furnaces are given. A section on protection of combusion-air piping systems against explosions is also included.—J.A L.

Rational Utilization of Gas-Burning Furnaces. M. Calmes. (Centre de Documentation Sidérurgique: Circulaire d'Informations Techniques, 1951, vol. 8, No. 3, pp. 305–320). This study is concerned with rapid methods of determining furnace performance by a summation of heat losses. Possible economies are compared with those actually achieved. Results are represented in tabular form for blast-furnaces, coke ovens, soaking pits, furnaces used in the manufacture of sheet iron, etc. Conditions which have to be satisfied for the efficient working of the furnaces are listed. If these are realized a saving of 1000 cu. m./hr. of blast-furnace gas should be possible.—P. F.

Single-Uptake Furnaces. A. H. Leckie. (Iron and Coal Trades Review, 1951, vol. 162, Mar. 30, pp. 751–754). The author gives a brief account of the history and development of the single air-uptake furnace as an illustration of co-operation in the industry through a B.I.S.R.A. research committee. At present, 18 single-uptake furnaces are operating in Britain, fired by oil or oil plus coke-oven gas, and the practical operation, simplification of design and conversion problems, and advantages obtained, are indicated.—G. F.

Experience with Flat Burners for a Reheating Furnace. F. Morawe. (Stahl und Eisen, 1951, vol. 71, Mar. 1, pp. 244–246). Results obtained with a flat gas burner, made in the steel firm's own workshop, have shown it to be superior to other types in simplicity, cheapness, and thermal efficiency. The burner has a glass port for observation of the flame.—J. P.

Forging Furnaces. F. K. Reintsch. (Die Technik, 1950, vol. 5, Dec., pp. 579–580). The report contains data for calculating furnace size and fuel consumption, and a recommendation is made not to rely on one fuel when laying down a new battery of furnaces. Rectangular hearths are preferred for the handling of large forgings and square ones for small forgings. The various firing methods are compared with reference to fuel difficulties in the East German Republic. Drawings are reproduced of a medium-sized furnace burning gas from a Siemens shaft producer and of another fired by gas or tar oil.—J. G. W.

A 4000° Furnace. W. E. Few and G. K. Manning. (Metal Progress, 1951, vol. 59, Mar., pp. 364–365). It should be realized that the furnace described in this article only heats to 4000° F. It consists of molybdenum used as heating element and radiation shields, inside a vacuum-tight water-cooled steel case. The power consumed is about 4·4 kW.—E. T. L.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat Treatments. N. N. Brown. (Machine Design, 1950, vol. 22, Oct., pp. 88–93; Nov., pp. 115–119; Dec., pp. 137–142). Part I, entitled 'Toughness,' deals with stress relieving, annealing, and normalizing of non-quenching types and the through-hardening of quenching types of steel; the avoidance of conflicting work specifications; and the effectiveness of heat-treated low-carbon alloys. Part II, entitled 'Hardness,' deals with case-hardening, distortion, and through-hardening. Part III deals with combining hardness and toughness, with particular reference to the hardening of thin sections, the standardization of specifications, low-distortion hardening, response to heat-treatments, and tempering requirements.—E. C. S.

The Heat-Treatment of Sheets. J. Magliano. (Rivista di Meccanica, 1950, vol. 1, Sept. 1, pp. 9–12). [In Italian]. A review is given of the most recent developments in the heat-treatment technique of steels. The methods described for tempering steels are based on experimental data and are proving increasingly valuable in assessing the characteristics of steels. The author recommends concentrating heat-treatment operations into a few specialized works—M. D. J. B.

Basis for New Methods of Heat-Treatment of Steels and a New Martensite Transformation Diagram. R. Mitsche. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1951, vol. 97, Feb., pp. 25–28). Some new viewpoints concerning the transformation of steels below the Ar_1 point are illustrated with reference to a eutectoid and tool steel (W 18%, Cr 4%, V 1%). The study of the transformation processes in the region of supercooled austenite has been confined in general to conditions in which the metal is either held isothermally or is allowed to cool gradually. The principle of the new method lies in modifying this treatment by introducing controlled rates of cooling and reheating varying from very slow to very rapid over given ranges of temperature. It is possible by means of **S**-curves, for example, by holding a eutectoid carbon steel for a suitable period (determined by its **S**-curve) just below the Ar_1 point so that no pearlite forms, and then by rapidly cooling it by a predetermined amount, to obtain spheroidal carbide. A number of such practically applicable heat-treatments are shown in eight illustrations. The martensite transformation, which take place at lower temperatures, is also discussed on a similar basis.—P. F.

A New Low-Temperature Treatment for all Ferrous Metals. (Métallurgie, 1950, vol. 82, Dec., p. 893). **The Sulfinuz Treatment to Prevent Frictional Wear.** (Revue Générale de Méchanique, 1951, vol. 35, Apr., p. 131). The 'Sulfinuz' treatment developed by the Société des Traitements de Surface is described. This process increases wear resistance without increasing surface hardness and reduces friction.

Treatment in a salt bath at 580° C. for 3 hr. enables sulphur compounds to penetrate deeply into all ferrous metals.—R. S.

Mid-Century Reference of Heat Treating. F. R. Morral. (Iron Age, 1951, vol. 167, Jan. 4, pp. 267–268, 448–462). A comprehensive index of references on time–temperature transformation reactions of both ferrous and non-ferrous metals is presented, and a cross reference of subject headings is included.—A. M. F.

Controlled Atmospheres. W. F. Ross. (Canadian Metals, 1951, vol. 14, Mar., pp. 12, 14, 50). Controlled atmospheres of special composition, used in heat-treatment, *e.g.*, for carburizing and nitriding metals to give the latter specific properties, are discussed. Characteristics of lean-ratio and rich-ratio exothermic, and endothermic or cracked atmospheres are considered and applications indicated.—E. C.

Recent Heat-Treatment Installations. (Metallurgia, 1951, vol. 43, May, pp. 221–233). This is a review of reheating, annealing, hardening, tempering, and gas-carburizing furnaces, as well as those recently erected for gas cyaniding, nitriding, steam treatment, and instructional work. There are 33 illustrations with detailed descriptions.—E. T. L.

Ford Bushings Heat-Treated Efficiently in Furnaces with Rotary Retorts. (Industrial Heating 1951, vol. 18, Jan., pp. 30–36). A description is given of a continuous automatic furnace installation at the Ford Motor Co., Detroit, for the hardening of small parts by gas carburizing. The installation, built by Surface Combustion Corporation, Toledo, consists of rotary retort carburizing and tempering furnaces with an automatic quench mechanism.—J. A. L.

Patenting Furnace Features Lightweight Construction. W. R. Bloxdorf and A. M. Naysmith. (Iron Age, 1950, vol. 166, Dec. 14, pp. 112–113). Three newly designed patenting furnaces for wire installed at the wire mills of Macwhyte Co., Kenosha, Wisconsin, are described. The use of light-weight insulating firebrick and a ventilated hearth reduces the heat capacity of the furnaces and allows for rapid changes in condition for various sizes and grades of steel. Fully automatic temperature control is incorporated to give increased fuel economy.—A. M. F.

Modern Heat-Treatment Applied to Spanish Special Steels. M. Torrado y Varela. (Instituto del Hierro y del Acero, 1950, vol. 3, Oct.–Dec., pp. 309–322). [In Spanish]. Following some general remarks on the isothermal transformation of austenite the author considers chronographic, isochronic, and iso-austenitic curves. The morphology of the constituents formed from the breakdown of austenite is examined. The different types of isothermal treatment are discussed, and, finally, their application to some Spanish carbon steels and chromium-molybdenum steels is described.—R. S.

The New Hardening Department of the N.V. Ijzergieterij en Machinefabriek Js. Zimmer en Zonen. (Metalen, 1951, vol. 6, Feb., pp. 43–44). [In Dutch]. This modern, hygienic, hardening department has an automatically regulated Smit salt bath and an underground waste canal system. Water- and oil-hardened parts can be used without further cleaning. No technical details are given.—R. S.

'Decarb' on Screw Products Yields to Controlled Atmosphere. J. E. Tschopp. (Machinist, 1951, vol. 95, Mar. 24, pp. 430–431). Carbon depletion of normalized screw stock may extend 0·007 in. below the surface. Threads rolled on such material develop suitable properties if the hardening furnace has carbon-restoring atmosphere. The use by The Chicago Screw Co. of a specially built 'Surface Combustion' atmosphere furnace with radiant tubes at its new plant at Bellwood, Illinois, is described.—E. C. S.

Progress in the Construction of Electric Furnaces: Improvement in the Gas Seal. F. Barbas. (Métaux et Industries, 1950, No. 1, pp. 24–32). The main difficulty with electric furnaces at present is oxidation, which is due to air infiltrating, especially round the doors. It is shown how a seal may be obtained by means of thin blades sliding in packing material. Using carbon monoxide, any oxygen remaining may be burnt. As well as saving heat, this prevents decarburizing and scaling, and machining costs are thus reduced.—N. McE.

Heat-Treatment of Armor Plate. H. Drever. (Industrial Heating, 1950, vol. 17, Dec., pp. 2106–2118). A description is given of the heat-treatment of armour plate less than 6 in. thick. A typical production line, consisting of hardening furnace, quench system, tempering furnace, and tempering quench systems, is described in some detail.—J. A. L.

Production Problems—1. Dimensional Changes in Gears and Pinions. (Iron and Steel, 1951, vol. 24, Feb., pp. 51–54). This investigation is concerned with the changes in dimensions of gears and pinions frequently encountered after production heat-treatment. These changes are caused by the non-uniform distribution of the internal stresses set up by unequal cooling due to the relatively sharp changes of section. Micro-examination of the gears and pinions shows that in many cases this unequal stress balance, which can be minimized by a low-temperature stabilizing treatment, is enhanced by variations in structure after heat-treatment. A carefully standardized heat-treatment will do much to eliminate the dimensional changes. The time of heat-treatment and rate of cooling are major factors.—G. F.

Heat-Treatment of Upsetting Dies. A. B. Frenkel. (Stanki i Instrument, 1948, No. 1, p. 28). [In Russian]. The heat-treatment of upsetting dies is considered and a description is given of a device for minimizing distortion.—S. K.

Through-Hardening and Heat-Treating of Steel by Means of Torches. H. Bühler and H. W. Grönegress. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 343–347). The results are reported of experiments into the flame-hardening and heat-treating of alloyed and unalloyed steels. Through-hardening of sections up to 80 mm. thick is possible if the hardening is carried out with coal-gas/oxygen flames and quenching sprays, the steel being drawn continuously through the flame and sprays. It is shown that flame tempering is also possible, so that a complete heat-treatment process can be performed without the use of a furnace. Heavier sections can be treated if the steel is given a pre-warming. Material processed in this way compares favourably as regards mechanical properties with that treated in a furnace. Flame heat-treatment of bars, tubes, sheets, and girders has shown that the process requires less time than that carried out in furnaces and is less costly in equipment. It has the advantage of being continuous and is readily adapted to changing production requirements.—J. P.

Heat-Treatments Accompanying Cementation. J. Pomey. (Métaux–Corrosion–Industries, 1951, vol. 26, Mar., pp. 97–125). This is a revue of the physics, metallurgy, and applications of cementation. Applied to low-alloy steels, followed by suitable heat-treatment, cementation can yield a case-hardened product superior in impact and fatigue strength to extra-hard steels. Compressive microstresses obtainable by cementation followed by quenching prevent quenching cracks and formation of microscopic fissures in the martensite plates. If a specimen is free from internal body stresses before cementation the case-hardening can be performed without distortion of shape. The effect of annealing conditions on the structure of special semi-hard steels and their machinability as related to the manner of annealing are discussed and illustrated by micrographs. Details appertaining to cementation in the production of gear wheels are explained. Metallurgical control, the rôle of nitrogen and the criteria of temperature and duration of treatments involved in cementation are considered together with problems connected with quenching, low-temperature cyaniding, and case-hardening by induction heating.—P. F.

Cementation by Carbon and Nitrogen. J. Pomey. (Métaux–Corrosion–Industries, 1951, vol. 28, Feb., pp. 49–80). An analysis of the processes involved in cementation is presented. It deals first with the chemical aspects of the problem and then with the diffusion of carbon and nitrogen in the metal. The decomposition into elements of methane and ammonia at the surface of the hot metal is discussed and questions relating to chemical equilibria, the cementation by carbon monoxide, the rôle of hydrogen in this type of cementation, the influence of free carbon on the rate of cementation, and carburization by organic substances are examined. The rôle of hydrogen in cementation by methane, the effect of traces of water vapour and carbon monoxide on the process, and cyaniding are also examined. The second part consists of a detailed theoretical treatment of the diffusion phenomena involved. The coefficient of diffusion is defined and, by a step-by-step method of approximation, the diffusion equation is solved. The insufficiency of the solution is pointed out and a more detailed approach on the basis of the De Dorn, Gier, Boetler, and Ward formula is presented. It is concluded that the theoretical basis of cementation can provide valuable guidance on a subject which for long has received but empirical treatment.—P. F.

Metallographic Study of Surface-Quenched Cylindrical Plain Carbon Steel Specimens. R. Quigna. (Métaux et Industries, 1950, No. 3, pp. 65–75 ; No. 4, pp. 83–91). The heat-treatment required by a specimen to give it a case of desired hardness and depth has to be determined generally from data or graphs obtained by previous heat-treatment experiments. The question whether the results of the Jominy test could be applied for the selection of appropriate heat-treatment for medium-carbon steels is examined. Specimens, about 2 in. in dia. and 2½ in. long were rotated axially over an oxy-acetylene burner for 24 sec., and immediately quenched by a water spray. No satisfactory correlation of hardness and case depth with those calculated from results of Jominy tests was obtained. This is explained by the heterogeneous heating and the short period of heat flow, owing to which the structure is not comparable with that obtained under different conditions in the Jominy test.—F. F.

Non-Remanent Iron and Its Heat-Treatment. R. Hartl. (Slaboproudový Obzor, 1950, vol. 11, Sept., pp. 161–166). [In Czech]. The author surveys recrystallization and annealing problems of non-remanent irons and reports the results of heat-treating the iron with restricted admission of air, in a protective hydrogen atmosphere, and *in vacuo*. The experiments were carried out to determine the correct recrystallization temperatures and to investigate grain growth. Magnetic and mechanical properties of some non-remanent irons are given.—E. G.

The Manufacture of Harrow and Plough Discs. (Coke and Gas, 1951, vol. 13, Feb., pp. 66–67). The flat discs, varying between 16 and 36 in. in dia. and from 10 gauge to ¼ in. in thickness, and of sheet steel (C 0·65 to 0·80%), are pressed into a dished shape at 900° C. The temperature of the discs on leaving the press is about 800° C., with the centre portions at a lower temperature than the edges. To make the process of 'catch-hardening' the edges consistent and controllable, the East Midland Gas Company has designed a 'furnace-less' flame-hardening unit which can be used for discs of various diameters. It is described in detail. After hardening, the discs are tempered at 360° C. in a gas-fired forced air recirculation oven, left to soak, and then cooled slowly.—T. E. D.

Hardening Tool Steels. P. Montereau. (Métallurgie, 1950, vol. 83, Jan., pp. 33–37, 42). The elementary principles of hardening are explained. Some general remarks are made on the elements of cost of hardening. The hardening of a mould for pressure casting a copper alloy is described.—R. S.

Furnace Economy, Effect of Improved Methods of Handling. J. M. McDonald. (Metal Treatment and Drop Forging, 1951, vol. 18, Apr., pp. 158, 159). This is a general and brief review of the necessity for efficiently designed furnaces, more consideration of heat loss, and better mechanical handling equipment in the heat-treatment field.—P. M. C.

How Furnace Moisture Causes Embrittlement. C. A. Zapffe. (Iron Age, 1950, vol. 166, Dec. 28, pp. 60–65). Research into the effects of moisture present in furnaces during heat-treatment has been carried out on a number of stainless steels. The extreme case of heat-treating in an atmosphere of steam at 1 lb. pressure has shown a very remarkable decrease in angle of bend in a bend test over that obtained from specimens heat-treated in a helium atmosphere. This is explained by the fact that hydrogen potential of steam contacting steel at elevated temperatures frequently exceeds that of pure hydrogen itself under theoretical pressures of hundreds and even thousands of atmospheres, thus intracrystalline hydrogen embrittlement readily takes place.—A. M. F.

Ford Transmission Shafts Gas Carburized in Automatic Furnaces. (Industrial Heating, 1951, vol. 18, Feb., pp. 216–228). A description is given of a furnace installation at the Mound Road plant of the Ford Motor Co., Detroit, for heat-treating approximately 480 shafts per hour. It consists of two carburizing furnaces and quench tanks, which are served by a washing machine and tempering furnace.—J. A. L.

Largest Automatic Gas Carburizing Installation at Warner Gear Plant. (Industrial Heating, 1951, vol. 18, Mar., pp. 410–420). A description is given of an installation at the plant of the Warner Gear Division, Borg-Warner Corporation, Muncie, Ind. The processing steps, heating, quenching, washing, drying, and drawing, which are all completely automatic, are described in some detail.—J. A. L.

Electron Diffraction Studies of the Case-Hardening of Iron by Carbon Monoxide. J. J. Trillat and S. Oketani. (Métaux et Corrosion, 1950, vol. 25, Oct., pp. 263–264). Electronic diffraction applied to very thin films of iron obtained by volatilization has enabled the mechanism of case-hardening to be investigated and has shown the different phases at different temperatures and for different methods of case-hardening.—R. S.

Localised Flame-Hardening of Steel Cutters Reduces Warpage. A. P. Alexander. (Materials and Methods, 1951, vol. 33, Mar., p. 76). The author describes the method employed for selectively hardening the cutting edge of baler knives by International Harvester Co. (U.S.A.). The knife blade, 12 in. long, ⅜ in. thick, and tapering from 4½ to 3½ in. in width, is made of a laminate of steel (0·90% C) for the cutting edge and low-carbon steel for the backing. The cutting edge is flame-heated whilst the backing portion is immersed in cooling water, after which the hardening is accomplished by oil-quenching.—P. M. C.

3 Million Axle Shafts Induction Hardened. S. L. Widrig and C. A. Payntor. (Iron Age, 1950, vol. 166, Dec. 21, pp. 69–73). The process of induction hardening used by the Salisbury Axle Division of the Dana Corp., Ind., is described. This method has been in use for four years and improved physical properties and reduced production costs have been obtained by using plain carbon steel instead of alloy grades. The shaft diameter varies from 1·094 to 1·625 in. but a uniform hardness depth can be maintained.—A. M. F.

Nitriding—Effect on Fatigue Strength of Stainless Steel. V. T. Malcolm and S. Low. (Journal of Metals, 1950, vol. 188, Sept., pp. 1094–1095). The 'Malcomizing' process is a method of nitriding stainless steels which involves the reduction by nascent hydrogen of the chromium oxide surface film, which prevents such steels from being successfully nitrided by conventional processes. The results of impact and fatigue tests on 'Malcomized' and un-nitrided stainless steels are given, showing that the fatigue strength of the material may be greatly increased by surface hardening.—G. F.

Carbonitriding and Related Heat Treating Processes. M. Neumeyer. (Industrial Heating, 1951, vol. 18, Feb., pp. 236–244). Carbonitriding, gas carburizing, and clean hardening methods of heat-treating steel are discussed. A description of furnace atmospheres, including gas generators and the constituents used, is given. The restoration of carbon to steel and the use of town gas for heat-treating atmospheres are dealt with.—J. A. L.

Kinetics of Decarburization of Transformer Steel during Annealing in Hydrogen. B. D. Averbuch and G. E. Chufarov. (Iron and Steel Institute, 1951, Translation Series, No. 422). This is an English translation of a paper which appeared in Metallurg, 1939, No. 7, pp. 48–61 (*see* Journ. I. and S.I., 1940, No. I, p. 144A).

The Annealing of Cast Steel. M. Guédras. (Métallurgie, 1950, vol. 82, Oct., pp. 755–758). The effects of temperature and duration of annealing and of the rate of cooling on grain refinement are discussed in relation to the annealing of castings. A useful type of 17-ton mobile-hearth annealing furnace is briefly described.—R. S.

Bright Annealing Furnace Installation. (Machinery, 1950, vol. 77, Nov. 30, pp. 559–560). The electric furnace equipment, for the bright annealing of wire, installed by The General Electric Co., Ltd. for Richard Johnson and Nephew, Ltd., is described. It consists of three vertical cylindrical 90-kW. furnaces, and 18 annealing containers 68 in. deep and 33 in. in dia. The furnaces operate at temperatures up to 750° C. and the power consumption, which varies with the time cycle and maximum temperature, is of the order of 200–220 units per net ton of charge.—E. C. S.

Quenching : Some Aspects of the Rate of Cooling in Various Media. (Iron and Steel, 1950, vol. 23, June, pp. 303–306). The mechanism of the quenching process and the various stages of the cooling curves obtained in quenching are discussed in detail. The factors affecting the maintenance and duration of the vapour film surrounding the metal are considered, and the important part played by these films during quenching is emphasized. Other aspects of the operation which are discussed are the flow of liquid past the surface of the metal, the surface condition of the metal, and possible surface activity.—G. F.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Ahead at Utica. W. Walker, jun. (Industrial

Heating, 1950, vol. 17, Nov., pp. 1920–1926). The author describes the forging of turbine and compressor blades at the Utica Drop Forge and Tool Corporation, New York. He is concerned mainly with the instrumentation and control aspects of the process.—J. A. L.

Spun Neutral Shapes Facilitate Drop Hammer Forging. G. C. Close. (Steel, 1951, vol. 128, Jan 22, pp. 72–74). Before drop-hammer forging, sheet metal can be spun to give a shape approaching that of the finished part desired, thus eliminating several sets of staging dies. During this 'prespinning' metal thickness and distribution can be controlled to minimize excessive local thinning and rupture during final hammer forging. Apart from aluminium alloys, terneplate, and carbon and stainless steels have been successfully fashioned in this way.—A. M. F.

Machine Utilisation and Plant Maintenance in the Drop Forging Industry. L. Robinson. (Metal Treatment and Drop Forging, 1951, vol. 18, Apr., pp. 160–162, 170). The author discusses the importance of maximum utilization of forging plant and auxiliary machinery to meet the increasing demand for forgings. Factors governing the production rate, and maintenance in a forge are described.—P. M. C.

The "Holtus" Bar Feeder. M. Colnel. (Centre de Documentation Sidérurgique: Circulaires d'Informations Techniques, 1951, vol. 8, No. 3, pp. 295–296). A feeder is described by means of which hot metal bars of rhombic, rectangular, or square section can be guided from one channel to another in hot-working operations. The essential part of the equipment consists of two electrically or hydraulically driven spinning tops, one having a straight vertical generator facing the other, the second being of parabolic cross-section and inclined towards the first. Both are provided with gear teeth on their surfaces and have several circular circumferential grooves. The bar to be transported sits in the wedge-shaped opening between the tops, being supported by their walls. It is held by the gear teeth and propelled forward by their rotation around the axes of the tops. The hydraulic type of equipment is more complicated than its electrical equivalent, and the latter is therefore preferred. A description of the maintenance routine is given.—P. F.

Estimating Forging Times. M. H. Wiegandt. (Machinery, 1951, vol. 78, Mar. 1, pp. 355–358). The floor-to-floor time required for a forging job can be expressed by: $T_t = T_s + T_f + T_l$ where T_t = floor-to-floor time; T_s = setting-up time; T_f = forging time, and T_l = lost time. Graphs relating these and other factors influencing forging time are presented.—R. A. R.

Modern Diesinking Practice. E. W. Peel. (Metal Treatment and Drop Forging, 1951, vol. 18, Mar., pp. 95–101). The factors affecting forging-die design are type of press or hammer, and the size, shape, and material of the forging. These are briefly discussed and the author then describes the stages in the diesinking process, *i.e.*, the shaping of die blocks, the marking out of impressions, the use of sheet metal templates and gauges, the vertical milling operation, and, finally, hand finishing by the skilled diesinker. Accuracy, tolerances, and hardness requirements are also briefly discussed, and three special milling machines are briefly described and illustrated—the Pratt and Whitney 'Keller,' the Cincinnati 'Hydrotee,' and the 'Gorton.' These machines copy or duplicate master dies.—P. M. C.

Investigations into the Causes of Drop Forging Faults. H. Rauhaus. (Metal Treatment and Drop Forging, 1951, vol. 18, May, pp. 205–213). This is an English translation of a paper which appeared in Stahl und Eisen, 1950, vol. 70, Mar. 30, pp. 252–264 (*see* Journ. I. and S.I., 1951, vol. 167, Jan., p. 92).

Determining Practical Forging Cost. J. J. Sloan and K. R. Denny. (Machine Design, 1950, vol. 22, Sept., pp. 151–152). Data are presented by which a comparison can be made between the costs of producing certain complicated metal components by machining and by forging from bar stock.—R. A. R.

The Sol-A-Die Process for Pressings. J. F. Tyrrell. (Machine and Tool Blue Book: Rivista di Meccanica, 1950, vol. 1, Oct. 1, pp. 14–16). [In Italian]. In this brief, illustrated article a description is given of the Sol-A-Die process of multi-stage drawing previously described by J. F. Tyrrell (*see* Journ. I. and S.I., 1950, vol. 166, Oct., p. 158).—R. A. R.

Cold-Rolled Strip and the Stamping and Cutting Industries. (Métallurgie, 1950, vol. 82, Dec., p. 973). Cold rolling permits any desired degree of work hardening to be obtained and provides uniform quality throughout a coil. This is a necessary requisite for cutting and stamping. This note enumerates some other obvious advantages of cold-rolled products required for cutting and stamping.—R. S.

Bending Presses with Plate Frames. (Ossature Métallique, 1951, vol. 16, May, pp. 229–230). Bending presses of 30, 50, and 100 tons as produced by Dutrannoit at Charleroi are described. Numerous parts usually made of steel or cast iron have been replaced by plate parts, resulting in a considerable reduction in weight and expenditure of material.—P. F.

Flow Test of Hubbing Steel. F. Halward. (Metal Progress, 1951, vol. 59, Mar., pp. 356–358). Hubbing is a process of pressing a hard 'hub' into a softer material, to produce a cavity of standard shape and size. The desirable characteristics of the material used for the hub are considered, in the case where it is of steel, and also of a softer die steel. The most important for the latter is the ease of flow, which can be tested by a simple procedure outlined here. The depth of penetration of a standard hub with a standard load, and the load needed for a standard depth of pentration are combined to give a proposed index of 'hubbability.'—E. T. L.

Testing the Deep-Drawing Capacity of Sheets—The Cupping Test and the Erichsen Bulge-Testing Procedure. G. Oehler. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, May, pp. 371–374). The history and essential details of the two tests are described, followed by a criticism of the relation of the tests to deep-drawing operations. Standardization of the procedures is recommended, particularly of apparatus for the cupping test.—J. G. W.

One Draw Reduces 40-in. Diameter Blank 60 Pct. G. Elwers. (Iron Age, 1951, vol. 167, Jan. 18, pp. 55–58). Cups 14½ in. in dia., 24½ in. long, with a nominal wall thickness of 0·10 in. are being successfully formed by reverse drawing by the Scaife Co., Pittsburgh. The material used is an annealed high-strength low-alloy steel, and this method of drawing allows the wall thickness to be maintained within ± 0·005 in.—A. M. F.

Cold Forging of Steel. V. Roger. (Métallurgie, 1950, vol. 82, Oct., pp. 781–783). This is an illustrated note on the cold-drawing process perfected by the Heinz Manufacturing Co. of Philadelphia.—R. S.

The Production of Shells by Cold Extrusion. (Machinery, 1951, vol. 78, Apr. 5, pp. 550*a*–550*e*). Mullins Mfg. Corp. has recently developed a process for the cold-extrusion of steel 105-mm. howitzer shells, Cold-extruded steel shells have a weight tolerance of ± 2 oz., a wall-thickness tolerance of ± 0·003 in., and a surface finish of 100 micro-inches root-mean-square (r.m.s.) or less, and each requires only 27 lb. of hot-rolled steel bar stock containing only 0·45% Mn approx., whereas the data for forged steel shells are ± 9·6 oz., 0·044 in., 250–500 microinches r.m.s., and 42 lb. respectively. Typical mechanical properties of a cold-extruded shell after a stress-relieving heat-treatment are: Yield strength (0·1% strain), 74,000 lb./sq. in., ultimate tensile strength, 87,000 lb./sq. in., elongation on 1 in., 15%, reduction of area 59%, and hardness, Rockwell B.91.—E. C. S.

Deep-Drawing Stainless Steel on Transfer Type Presses. (Machinery, 1950, vol. 77, Oct. 5, pp. 387–390). Automatic multiple-die, transfer-type presses, made by the Waterbury Farrel Foundry and Machine Co., are employed by the Advance Stamping Co., U.S.A., for deep-drawing stainless-steel parts from thin strip. Small parts are formed by rapidly moving them between the multiple dies on the press. The need for cleaning and annealing between drawing operations is eliminated. Austenitic 18/8 steel is preferred but the straight, high-chromium steel can also be drawn satisfactorily.—E. C. S.

Deep-Drawing with Rubber Press Pad. R. Bianchi. (Rivista di Meccanica, 1950, vol. 1, Sept. 1, pp. 23–28). [In Italian]. This article describes a method developed by the Glenn Martin Company for deep drawing by means of a rubber press pad: (*See* 'Marform. A New Press Drawing Tool,' by T. E. Lloyd, Journ. I. and S.I., 1950, vol. 166, Sept., p. 96).—R. A. R.

Modern Wire Drawing Machinery. A. Frascio. (Rivista di Meccanica, 1950, vol. 1, Dec. 1, pp. 5–10; Dec. 15, pp. 4–10). [In Italian]. A comprehensive review is given of wire-drawing equipment and methods from the first machines to the most up to date. The author covers the modern multiple wire-drawing machines for producing wires of all thicknesses,

qualities, types, and hardness in iron, steel, copper, aluminium, zinc, and lead. Tables containing technical data of modern multiple immersion and non-slipping wire-making equipment are given with line diagrams showing the design features of the different machines.—M. D. J. B.

ROLLING-MILL PRACTICE

Characteristics of Roller Table Drives in Rolling Mills. T. Sluszkiewicz. (Hutnik, 1951, vol. 18, Apr., pp. 151–154). [In Polish]. A description of different kinds of roller-table drives used in rolling mills and a comparison of their behaviour with individual and section drives is given. The electric drive and speed regulation are discussed.—V. G.

Calculation of Deformation Resistance and Power Requirements in Rolling. A. Geleji. (Acta Technica Academiae Scientiarum Hungaricae, Budapest, 1950, pp. 1–31). [In German]. A theory of rolling developed by the author (*see* Journ. I. and S.I., 1948, vol. 160, Oct., p. 225) is extended. It is proved that slipping between the roll face and metal always occurs. The forces and power requirements involved are derived on the basis of the relative movement of rolls and material being rolled. The power is the sum of the work of deformation and of friction. The mean deformation resistance is defined as (roll pressure)/(area in contact with the roll) and a formula is given to enable it to be calculated. Since the mean deformation resistance so defined contains the frictional work expended over the surface of contact, no account need be taken of frictional forces in calculating power required and formulæ are derived after making some simplifying assumptions. In practice, these need to be modified by a correction factor which depends on percentage reduction. If the rolls are not cylindrical, then frictional work arises which is not included in the calculated deformation resistance and this must be added to the work of deformation. Procedures are given for calculating this frictional work for simple passes. The calculation of the deformation resistance in grooved rolls allows the power requirements for square, oval, and round passes to be estimated.—J. P.

The Effect of Tension on Torque and Roll Force in Cold Strip Rolling. W. C. F. Hessenberg and R. B. Sims. (Journal of The Iron and Steel Institute, 1951, vol. 168, June, pp. 155–164). The rolling of mild-steel strip with front and back tension has been studied on the B.I.S.R.A. experimental rolling mill, to determine the effect of tension on the roll force and torque and, if possible, to suggest quantitative relationships between these variables. Simple approximate formulæ for calculating the effect of tension on roll force and torque are proposed, and comparison is made between calculated and experimental results. The difficulties inherent in more elaborate methods of calculation are discussed. The energy of rolling is composed of the energy required to deform the strip and the energy absorbed in overcoming friction between the strip and the rolls. Since the former depends only on the properties of the strip and the amount by which it is deformed, any effect of tension on the energy of rolling must arise from changes in the frictional component. In most cases this component is relatively small, and the experimental results confirm that the total energy of rolling is, for all practical purposes, unaffected by the application of tension.

What Problems Can Be Solved by an Experimental Rolling Mill? Z. Wusatowski. (Biuletyn Informacyjny Głównego Instytutu Metalurgii, 1951, No. 3–4, pp. 9–14; Hutnik, 1951, vol. 18, Apr.). [In Polish]. Various theoretical and practical problems which can be solved with an experimental rolling mill with adequate instrumentation are discussed.—V. G.

Position of the Use of Machinery in the Iron and Steel Industry. P. Voltz. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, May 1, pp. 341–348). This is a cursory survey of recent trends in mechanical engineering in the German iron and steel industry. The greater part of the article is devoted to rolling-mill layout and design.—J. G. W.

Considerations of Continuous Sheet Mills and the Possibility of Their Application in Spain. I. Sans Darnis. (Instituto del Hierro y del Acero, 1950, vol. 3, Oct.–Dec., pp. 270–281). [In Spanish]. The features of continuous and semicontinuous sheet mills are outlined. Furnaces, scale-breaking, and slabbing and finishing stands are then described in detail. Finally, the following points are discussed: Slag sizes in relation to dimensions of finished sheet, edging, and squeezers. Spain hopes to produce 1,800,000 tons of steel in 1960 and it is thought that she could make good use of a continuous sheet mill producing 200,000 to250,000 tons/annum of sheets 1 m. wide—R. S.

Cold Rolling with Strip Tension. Part I—A New Approximate Method of Calculation and a Comparison with other Methods. H. Ford, F. Ellis, and D. R. Bland. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 57–72). It is shown that, by making certain approximations to Orowan's general theory of rolling, it is possible to calculate roll force and torque by a method which is both rapid and easy to apply, using the basic information on the yield-stress characteristic of the material to be rolled, the coefficient of friction, and the dimensions of the pass. The roll force and roll torque functions used in the calculations are presented in graphical form, the particular values required being read off from the curves in terms of the pass dimensions. Various methods of calculating these quantities for strip rolling with tensions have previously been put forward, and this paper examines the methods of Orowan, Hill, Siebel, Tselikov, and Nádai, and compares them with the new method for a wide range of tensions. The new method can be more quickly applied than any of the other methods examined.

Montataire—The First French Continuous Cold Rolling Mill. M. Marie. (Métallurgie, 1950, vol. 82, Nov., pp. 843–850). This description of the Montataire works of the Usinor group covers the following equipment: Rolling mills, shears, electrical equipment, continuous pickling plants, gas producers, annealing furnaces, boilers, compressors, overhead travelling cranes, skin-pass mills, flatteners, and de-coilers. Raw material is hot-rolled sheet 2 to 4·5 mm. thick in coils of up to 18 tons. Sheets are pickled, rolled, and annealed. Some qualities are skin-passed. Speed through the continuous pickling tanks is 100 m./min. at 100° C. The mill consists of three stands in tandem.—R. S.

Causes of Fracture of Rolling-Mill Rolls. M. R. Edelbloude. (Centre de Documentation Sidérurgique: Circulaire d'Informations Techniques, 1951, vol. 8, No. 3, pp. 297–298). Eight illustrations of typical fractures occurring in rolling-mill rolls are given and the origin of each type is indicated.—P. F.

MACHINERY FOR IRON AND STEEL PLANT

Portable Shear Handles 1-Inch Rod. E. Jasper. (Iron Age, 1950, vol. 166, Nov. 23, pp. 74–76). A new portable unit capable of cutting rod and bars up to 1$\frac{1}{16}$ in. in dia., wire rope up to 1$\frac{1}{4}$ in. in dia. and cable up to 3$\frac{1}{2}$ in. in a cutting cycle of 2$\frac{1}{2}$ sec. is described. The cutter is semi-portable, weighs 38 lb. and is connected to a hydraulic pump, capable of developing 10,000 lb./sq. in., by 25 ft. of hose. The cutting cycle requires only a momentary surge of pressure from the pump and thus it is not continuously loaded and maintenance is at a minimum.—A. M. F.

Portable Ingot Stripper Offers Flexibility. (Iron Age, 1950, vol. 166, Nov. 23, p. 71). A portable ingot stripper for use with a general service crane is described. The unit is hydraulically operated and entirely self contained, only an electrical power connection being required. It can handle moulds from 37$\frac{5}{8}$ to 52 in. over the cars—A. M. F.

Chilean Mill Uses Novel Bloom Shear. (Iron Age, 1950, vol. 166, Nov. 16, p. 96). The new integrated steel mill of Acero del Pacifico, Chile, is operating a down-cutting bloom-shear employing a hydraulically operated hold-down 'gag' which automatically adjusts both itself and the stroke of the depressing table to the thickness of the slab. Advantages are a clean square cut and reduction of maintenance costs on both the depressing and shear approach tables.—A. M. F.

WELDING AND FLAME-CUTTING

Welding Progress—Research and Development. (Commonwealth Engineer, 1951, vol. 38, Apr. 2, pp. 342–345). Various aspects of welding practice are reviewed. The weldability of three chromium–molybdenum steels is discussed in detail. Investigations carried out by The United Steel Companies, Ltd., show that the preferred maximum carbon contents for good weldability of these steels would be: 1% Cr, 0·5% Mo steel, 0·15% C; 2·25% Cr, 1·0% Mo steel, 0·10% C; and 5% Cr, 0·5% Mo steel, 0·08% C.—T. E. D.

Cost of Welding Stabilized Stainless. D. W. McDowell, jun. (Metal Progress, 1951, vol. 59, May, pp. 650–652). This is a report of experiments on the relative merits of titanium and columbium-stabilized stainless steel. It is concluded that the former gives cheaper and better welds for both inert arc

and metallic arc welding. Of these two types of welding the inert arc method gives stronger joints, and is quicker and cheaper.—E. T. L.

The Development of Welding Rods for the Oxy-Acetylene Welding of Steel. C. G. Keel. (Doctorate Thesis, Eidgenössische Technische Hochschule, Zürich, 1950, pp. 1–51). Twenty-six types of welding rod of differing compositions were used for the preparation of V-welds in 10 × 8 × ¼ in. mild-steel plates. The welds in one set of plates were torch-annealed, but those in the other set were not. Twelve test strips having the welds at the centres were cut from each plate and 3–6 strips of each plate were subjected to notch impact tests. On the basis of high impact strength in the torch-annealed and non-annealed conditions three rods were selected for further study. These were low-alloy rods including a Mn–Cr–Cu steel, a Mn–Mo steel and a Mn–Cu steel, all low in carbon and silicon. The joints in plates, as well as specimens cut from the actual welds made with these three steels, were then subjected to hardness and tensile tests at low, room, and high temperatures, and to impact and fatigue tests. The experimental results are given graphically and in tabular form. It is concluded that the three types of welding-rod selected are capable of yielding welds as good, and in general much better, than are demanded by the strictest specifications for this type of welding in modern practice. Results obtained by arc welding are shown to be in every respect equivalent to those obtained with the oxy-acetylene torch.—P. F.

Testing the Susceptibility of Weldable Structural Steels to Brittle Fracture. E. Folkhard. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 347–351). When testing for susceptibility to embrittlement after welding, it is essential that the steel should be in the same state of polyaxial stress as results from welding. It is shown that the tendency of a steel to form cracks after welding and to become embrittled are two fundamentally different properties. Tests have been carried out to determine the degree of bending to which specimens of steel (0·04% C, 0·41% Mn) carrying a longitudinal welding bead, could be subjected before brittle fracture. Impact strengths were determined on Schnadt and standard notched bar test pieces and values of reduction of area on Kinzel specimens. The first two types of specimen did not show up factors known to affect the degree of weld embrittlement, but a good correlation was found between the welded bead bend and the Kinzel test, particularly if the latter was carried out at a temperature 10° C. lower than the former.—J. P.

New Methods of Testing Metals and Their Application to Welded Construction. J. J. L. van Maanen. (Revue de la Soudure, 1951, vol. 7, No. 1, pp. 1–15). The author, a collaborator of M. H. M. Schnadt, gives a description of the latter's new theories on the failures and general behaviour of metals. The classical theories no longer suffice to explain a number of problems which occur in welding and the new and original ideas of Schnadt afford an explanation of the behaviour of metals and a solution to some of the more complex problems of welding. Plastic deformation and Schnadt's polyaxis abacus are considered together with the fundamental diagram of a metal. The 'St Venant' new practical unit of the plastifying characteristic and lastly Schnadt's specimens are discussed. A key is given to Schnadt's nomenclature.—M. D. J. B.

MACHINING AND MACHINABILITY

Machinability Data for High-Temperature Alloys. R. le Grand. (Machinist, 1951, vol. 95, Mar. 3, pp. 305–312). Some results of a machinability-research project by the Curtiss Wright Corp. for the U.S. Air Force are presented. A table gives the physical and machining properties of jet-engine alloys. The estimation of the machinability of jet-engine alloys is explained.—E. C. S.

How to Drill Hardened Steels. R. Double. (Machinist, 1951, vol. 95, Mar. 3, p. 313). Hardness up to Rockwell C65 in tool-steel parts may be overcome with a special drill. The Westinghouse Electric Corp. have found that a carbide-tipped twist drill can operate efficiently through hardened high-carbon steel without killing the temper at the edge of the hole. The drill has a 130° included angle, positive rake, and 12° clearance. The shank is of high-speed steel with two flutes with the conventional twist.—E. C. S.

Electric Strain Gage Tool Dynamometers. E. G. Loewen, E. R. Marshall, and M. C. Shaw. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 1–16). In this article a number of dynamometers utilizing electrical resistance strain gauges are described. These have been used to measure and record as a function of time the forces exerted upon metal cutting tools during the following machining operations: Planing, drilling, grinding, and turning. The bridge circuits used with each of the dynamometers and the mechanical aspects are described. Design details of the load-measuring elements employed and the advantages and disadvantages of several measuring instruments available for use with strain gauge bridges are discussed.—P. M. C.

CLEANING AND PICKLING

The Present Position of Industrial Electrolytic Polishing. P. A. Jacquet. (Metalloberfläche, 1950, vol. 4, June, pp. A81–A92). After a short historical introduction the author reviews industrial applications of electrolytic polishing and compares the merits of electroytic and mechanical polishing. Special applications of electrolytic polishing mentioned are: Improvement of optical qualities; treatment of semifinished products; surface preparation for electroplating; superfinish of mechanical working parts; treatment of vacuum-tube cathodes; improvement of magnetic or electrical properties; and shaping metal needles. There are 34 references.—O. H. G.

Steel Pellets: British Hard-Drawn Product for Cleaning and Peening. J. E. Hurst. (Iron and Steel, 1951, vol. 24, Mar., pp. 87–88). The author discusses the use of hard-drawn steel pellets, now made in England, for cleaning and peening purposes. The advantages of using cylindrical pellets instead of shot are enumerated.—G. F.

The Effects of the Pickling Process on the Amount of Hydrogen Occluded in Steel Plate for Porcelain Enamel. I. Sawai and M. Tashiro. (Memoirs of the Faculty of Engineering, Kyoto University, 1951, vol. 13, Mar., pp. 70–76). By direct estimation of hydrogen in enamelling steel of composition C 0·06, Si 0·05, Mn 0·44, P 0·04, Cu 0·32% by vacuum heating the following facts were ascertained: (1) Hydrogen absorbed by thin plate (0·56 mm.) during pickling in 10% H_2SO_4 can be removed by normal after-treatment; thicker plate (6 mm.) retains some of its hydrogen after similar treatment. (2) The after-treatment cannot be simplified. (3) If the plate contains cavities, some of the hydrogen cannot be removed even by prolonged heating at 70° C.—T. E. D.

PROTECTIVE COATINGS

Can Dross Be Eliminated in Hot Dip Galvanizing. W. G. Imhoff. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950, pp. 102–113). **Liquid Flux Technique Reduces Dross Formation.** W. G. Imhoff. (Steel, 1950, vol. 127, Dec. 25, pp. 62–64). The problems of dross formation in galvanizing baths are briefly discussed. Any corrosion that occurs between the pickling and galvanizing baths is a source of dross and may be largely eliminated by a dip, after pickling, in a solution of zinc–ammonium chloride of high enough concentration to cover completely the surface with a transparent film. This prevents any oxidation of the surface by exposure to air before galvanizing.—A. M. F.

Origin and Use of Clad Steel Plate. W. G. Theisinger. (Sauveur Memorial Lecture: Metal Progress, 1951, vol. 59, May, pp. 671–672, 708–716). Low-alloy steels covered with stainless steel give protection at relatively low cost, and after considerable research were available in 1930. While the range of claddings has widened since then the basic process is the same. Two slabs of the backing steel are cleaned, and on each is placed a sheet of nickel-coated facing metal. These two sheets are then placed together, separated only by a paste-and-powder mixture called a 'parting compound,' giving a sandwich with the steel outside. After sealing up the edges, the bloom is rolled down hot. Then the edges are cut off and the two halves of the sandwich separated. The author deals with the problems associated with the parting compound, the nickel plating, and the cleaning of the base metal. Applications of cladded metal are discussed.—E. T. L.

Metallic Soaps and Their Applications in Paint. F. Margival. (Peintures, Pigments, Vernis, 1951, vol. 27, June, pp. 352–355). The methods of preparation and the general properties of metallic soaps, including their solubilities in various solvents are described. Their applications in the paint industry can be summarized: (*a*) As setting agents which bring about the

resinification of oils ; (*b*) as anti-fouling agents ; (*c*) as stabilizing agents for avoiding sedimentation of pigments ; (*d*) for producing mat surfaces ; and (*e*) in priming paints. Examples of these and other applications are included.—T. E. D.

Protection of Structural Steel against Atmospheric Corrosion. J. C. Hudson and W. A. Johnson. (Journal of the Iron and Steel Institute, 1951, vol. 168, June, pp. 165–179). In this joint paper the protection of new structural steel against atmospheric corrosion is considered from two points of view. In the first part the approach is mainly theoretical and a brief account is given of the general principles that should be followed, as now established by the results of research. The approach in the second part is essentially practical. In it ways and means are considered by which these principles may be put to industrial use, bearing in mind the limitations and difficulties that are unavoidably imposed by industrial conditions. The conditions which a 'mass-produced' coating should fulfil, and some dependable coatings, which are assumed to be painted later, in the usual way, are discussed.

Tests on Anti-Rust and Anti-Corrosion Paints for Marine Use. H. Rabaté. (Peintures, Pigments, Vernis, 1951, vol. 27, Apr., pp. 205–211). A general picture is given of types of breakdown of paint surfaces and their causes, with particular reference to breakdown caused through attack by sea water. A report on preliminary work is included, and an account is given of laboratory tests, both accelerated and of long duration, that can be made on paint surfaces.—T. E. D.

Blistering Phenomena of Paints in Marine Environments. W. G. O'Driscoll. (Journal of The Iron and Steel Institute, 1951, vol. 167, Apr., pp. 353–357). An investigation of the blistering of chlorinated-rubber-based paints, applied to mild-steel panels, immersed in $N/2$ sodium chloride has demonstrated the presence of electrolytes within the blisters. The anodic or cathodic origin of the blisters is illustrated by potential plots over a blistered surface using a silver/silver-chloride electrode. To obtain blistering it is not necessary for the anodes and cathodes to be located on the same plate. The mechanism of blistering of paints on a steel surface immersed in sea water is discussed.

POWDER METALLURGY

Graphical Representation of Properties of Sintered Materials by Means of a General System of Co-ordinates Related to the Fully Dense Material. G. F. Hüttig. (Powder Metallurgy Bulletin, 1951, vol. 6, Apr., pp. 7–12). A graphical method of demonstrating the variation of a characteristic property (*e.g.*, electrical conductivity) of a sintered metallic material with 'degree of space filling' and method of preparation or pretreatment are described.—T. E. D.

The Effect of Pore Volume of Sintered Materials on the Magnetic Characteristics. K. Torkar. (Powder Metallurgy Bulletin, 1951, vol. 6, Apr. pp. 13–17). The saturation varies proportionally to the density of sintered pure iron, and deviations are due to oxide inclusions. Residual induction and coercive force are also studied with respect to their relation to the pore volume, and an analysis of magnetically effective pores is attempted.—T. E. D.

Sintered Nickel Steels. F. Benesovsky. (Powder Metallurgy Bulletin, 1951, vol. 6, Apr., pp. 18–21). The density of sintered nickel steels increases with increasing nickel content but is not influenced by carbon content. In carbon-free nickel steels the hardness increases with increasing nickel content, but maxima are observed for sintered nickel steels with 0·4% and 0·7% C. Steels containing 0·4% C have hardness maxima at 10 to 12% Ni and those containing 0·7% C at 8 to 10% Ni. Similar maxima are observed in the tensile strength values. Elongation is also affected by structure. If good diffusion is provided by high sintering temperatures and long sintering times, sintered alloys closely resemble the respective cast alloys. Single and double pressed alloys were investigated.—T. E. D.

An Investigation of the Effect of Final Density of Copper Infiltrated Iron on Physical Properties. G. Stern. (Powder Metallurgy Bulletin, 1951, vol. 6, Apr., pp. 57–62). Results obtained indicate that : (1) The higher the skeleton density, the higher will be the yield and tensile strength of the infiltrated material ; (2) the more perfect the infiltration, the higher the strength will be ; (3) for each skeleton density the yield point remains constant after 75% infiltration ; (4) for skeleton densities of 80, 85, and 90%, the tensile strength remains constant after 75% infiltration ; (5) below 90% final density the yield point is very near the ultimate tensile strength ; (6) the higher the skeleton density, the higher will be the hardness ; (7) the hardness increases with degree of infiltration up to 75% ; and (8) by the infiltration process a complicated shape can be formed with varying density in various sections, but the infiltration itself will equalize the physical properties in these sections.—T. E. D.

Infiltrated Iron and Steel : Recent Improvements in Physical and Mechanical Properties. H. W. Greenwood. (Iron and Steel, 1951, vol. 24, Mar., pp. 97–98). The author discusses the improvement in physical and mechanical properties of iron and steel compacts resulting from the infiltration or impregnation of the porous compact with a lower melting-point metal such as copper. The outstanding benefits are greater density and greater tensile strength, and examples of the improvements obtained in typical compacts are given. Possible applications of such compacts are also briefly discussed.—G. F.

PROPERTIES AND TESTS

The Influence of Liquids on the Strength and Dimensions of Solids. C. Benedicks. (Teknisk Tidskrift, 1949, vol. 79, Feb. 12, pp. 97–100). [In Swedish]. A melting liquid applied to the surface of a solid reduces the tensile strength of the solid. The greater the surface tension of the liquid, the more pronounced reduction can be expected. As a consequence of the diminished surface cohesion forces, an elongation of the solid takes place (liquostriction) ; this phenomenon is reversible. The data given represent an experimental confirmation of the author's theory that increased strength caused by adsorbing liquids is conceivable.—B. S. E.

Young's Modulus and Its Temperature Dependence in 36 to 52% Nickel–Iron Alloys. M. E. Fine and W. C. Ellis. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1120–1125 ; Journal of Metals, 1950, Sept.). A study of the effect of temperature, cold working, and annealing on the Young's modulus and thermoelastic coefficient of nickel–iron alloys containing 36–52% nickel, is described. It is shown that, at a certain temperature, depending on the composition and on the straining and annealing history, the normal decrease in Young's modulus is exactly compensated by an increase due to loss of ferromagnetism, thus resulting in a zero thermoelastic coefficient. The temperature range of low coefficient is greatly increased by cold work. The theory of the behaviour is discussed, and the dependence of the modulus on temperature is explained on the bases of the direct effect of the energy of ferromagnetism on the modulus, and of the stress-produced linear and volume magnestostriction.—G. F.

Factors of Stress Concentration in Bars with Deep Sharp Grooves and Fillets in Tension. M. M. Frocht and D. Landsberg. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 149–162). Factors of stress concentration for deep, sharp, and symmetrically arranged grooves and fillets in tension members have been determined photoelastically. The range of r/d values covered in this investigation is from 0·011 to 0·08, for $D/d = 1{\cdot}5$ and 2. (D = maximum width of model, d = minimum width through discontinuity, and r = radius of groove or fillet). Photoelastic fringe patterns are shown, and the results indicate that in both grooves and fillets, the factors of stress concentration increase sharply as r/d becomes less than 0·05, and also increase with the ratio D/d. The effect of grooves is considerably greater than the effect of fillets.—P. M. C.

Isopachic Patterns and Principal Stresses in Bars with Deep Notches in Tension. M. M. Frocht and E. Sevin. (Proceedings of the Society for Experimental Stress Analysis, 1951, vol. 8, No. 2, pp. 171–186). The authors deal with principal stresses and complete isopachic patterns, (which show the values of the sum of the principal stresses throughout the system) for bars in tension containing deep sharp notches. Starting with the free boundary stresses, (obtained from photoelastic experiments) the above data were determined by the numerical solution of Laplace's equation by combining the process of iteration with conformal transformations. Patterns are given for $r/d = 0{\cdot}0159$ and 0·238 when $D/d = 2$, and for $r/d = 0{\cdot}0222$ and 0·0447 when $D/d = 1{\cdot}5$ (D = maximum width of specimen, d = minimum width at root of notch, and r = radius at root of notch). The authors outline the process of iteration and of conformal transformation by means of bipolar co-ordinates.—P. M. C.

Intelligent Testing and Inspection of Forgings Assures High Quality at Lower Cost. L. F. Spencer. (Materials and Methods, 1951, vol. 33, Mar. pp. 77–80). The importance of regular dimensional checking, metallurgical examination, and physical and non-destructive testing during the production of forgings is discussed in a general manner. The author indicates the usefulness of, and methods employed for, the following: Hardness, tensile, bend, fatigue, and impact tests; macro-etching; metallographic examination; magnetic particle, fluorescent dye, and X-ray inspection; and finally the Jominy hardenability test.—P. M. C.

A New Dynamic Method of Measuring Elastic Constants. R. Cabarat. (Métaux–Corrosion–Industries, 1951, vol. 26, Mar., pp. 126–130). A cylindrical specimen, $\frac{1}{2}$ in. in dia. and 10 in. long, of the metal to be tested is held vertically in the apparatus by three hardened steel needles applied to it at the circumference and at the centre. The bar is placed into a furnace and an alternating electric field is applied to it by means of two electrodes connected to a generator, one electrode facing each end. The generator frequency is variable, and the amplitude of oscillation of the bar as a function of frequency is determined. From the peak in this curve the resonance frequency of the bar is found and, the density of the metal being known, the elastic modulus E is determined from the classical relation between these three quantities. An accuracy of about 0·3% is claimed. The equipment is suitable for the determination of internal friction. A detailed drawing and a photograph of the apparatus are shown.—P. F.

The Yield Point of Mild Steel at Non-Homogeneous and Compound Stress Distributions. F. K. G. Odqvist and C. Schaub. (Acta Polytechnica, Mechanical Engineering Series, 1951, vol. 1, No. 11). A new theory for the apparent yield point of mild steel at non-homogeneous and compound stress distributions is advanced, the flow limit being associated with the spreading of flow layers through part of the section of the test piece. The theory involves a material constant d, which may be determined either from macroscopic measurements or from X-ray measurements of the stress distribution preceding the spreading of flow layers.

The Plastic Theory of Bending of Mild Steel Beams with Particular Reference to the Effect of Shear Forces. M. R. Horne. (Proceedings of the Royal Society, Series A, 1951, vol. 207, June 22, pp. 216–228). While the simple plastic theory of bending gives a satisfactory explanation of the observed behaviour of mild-steel beams, it is open to various theoretical objections. These are examined by reference to the theory of perfectly plastic materials, and a special examination is made of the effect of shear forces, for which no allowance is made in the simple theory. The results are applied to beams of both rectangular and **I** section, and it is shown that the error involved in using the simple theory is small except for very short members. Experimental confirmation of the predicted configuration of slip surfaces in the web of an **I** beam is obtained by reference to tests performed by Frankl on welded connections.

Relation of Structure of Stainless Steel to Hot Ductility. F. K. Bloom, W. C. Clarke, jun., and P. A. Jennings. (Metal Progress, 1951, vol. 59, Feb., pp. 250–256). The metallographic structure of various steels for forging is related to results from a hot twist test. In this, one determines the number of twists of a hot bar needed to fracture it. Maxima in the curve of hot twist strength against temperature are due to phase changes in straight chromium steels, and chromium–nickel steels. A mixture of austenite and ferrite gives a lower ductility than either alone. In straight chromium steels the ferrite is the more ductile, while in chromium–nickel steels delta ferrite is harmful to hot ductility.—E. T. L.

Notched-Bar Impact Strength and Ageing Tendency of Rolled Steel Sections. E. Uhlir. (Betrieb und Fertigung, 1950, vol. 4, Mar., pp. 39–42). Notched-bar impact test pieces were cut from different parts of rolled angles, tees, and broad-flanged beams of unkilled mild steel. They were tested in the as-rolled condition, after a stress-relieving anneal, and after quenching and tempering. Further specimens, after subjection to each of these treatments, were artificially aged by cold stretching followed by low-temperature heat-treatment before testing. As rolled, all the sections were tough at the toes but had a brittle zone in the centre, and the whole section was embrittled by ageing. Stress annealing slightly improved the material at the toes but not at the centre, and did not affect the ageing tendency. Quenching and tempering improved the core material, making it nearly as tough as the toe material; it also greatly reduced the ageing embrittlement at the toes, but left the core material still just as sensitive to ageing. Since the grain size after quenching and tempering was the same thoughout the section, it is no guide to the tendency to ageing.—H. R. M.

Explosive Forces Widen Metallurgical Studies. (Steel, 1950, vol. 127, Nov. 20, pp. 98–99). Explosive charges, which can produce extreme pressures of up to 5,000,000 lb./sq. in. and of a duration of about two-millionths of a second, are being used to provide information which may be of advantage to metallurgists by shedding light on the resistance of metal to shock and impulsive loading.—A. M. F.

Three-Dimensional Photoelasticity. A. J. Durelli and R. L. Lake. (Machine Design, 1950, vol. 22, Dec., pp. 122–125). Research conducted at Armour Research Foundation in 1949 on the creep nature of some photoelastic materials shows that creep, when properly used, may be an advantage, not a disadvantage. In Catalin, a transparent phenol-formaldehyde, stressed up to about 1000 lb./sq. in. at room temperature, optical creep is linearly proportional to stress. Photographs of this material (*a*) immediately after loading, (*b*) 2·5 hr. after loading, (*c*) 22 hr. after loading, and (*d*) immediately after unloading, show that the only change with time was the fringe value or optical sensitivity, and that all fringe patterns correspond to an elastic distribution of stresses. The creep-freezing method is valid for those cases in which boundary conditions do not change during the course of the test.—E. C. S.

Recent Results from Photoelasticity Research. L. Föppl. (Teknisk Tidskrift, 1950, vol. 80, Apr. 29, pp. 383–388). [In Swedish]. The author outlines the field of photoelasticity, and describes a special method for three-dimensional photoelastic study. A model made of certain plastics is warmed to about 80° C., and, under the stresses applied, cooled down to room temperature. The optical effects due to the stresses remain in the material, which can even be sectioned for examination.—B. S. E.

Effect of Chromium Plating on the Plastic Deformation of SAE 4130 Steel. H. L. Logan. (Journal of Research of the National Bureau of Standards, 1951, vol. 46, June, pp. 472–479). The effects of chromium plating on the plastic deformation of SAE 4130 steel, hardness Rockwell C40, have been evaluated from the results of tensile, tensile impact, bending, and crushing tests. Chromium plating materially reduces the percentage of elongation, true stress at the beginning of fracture, and the ratio of the original cross-sectional area to the area at the beginning of fracture. Values of these properties decreased with increased plating thickness. Baking after plating generally increased the ductility of the plated steel. The tensile and yield strengths in tensile tests and the elongation and reduction in area of tensile impact tests were generally reduced less than 10% by chromium plating and were changed only slightly by baking after plating.

Some Extensions of Elementary Plasticity Theory. F. Edelman and D. C. Drucker. (Journal of the Franklin Institute, 1951, vol. 251, June, pp. 581–605). A detailed investigation is presented of yield or loading criteria, for work-hardening materials, which lead to constant strain ratios under increasing stress when stress ratios are maintained constant. The experimenter is given a choice of incremental stress/strain theories with which results of simple or complicated combined loading tests may be correlated. These theories are dealt with in order of increasing complexity and, at the same time, increasing capacity to represent experimentally established phenomena. The objective is the use of the mathematically simplest theory which will provide the desired flexibility in the analysis of experimental data. Loading functions of isotropic as well as anisotropic types are examined, among them those depending explicity on stress alone and those depending on both stress and plastic strain. In the latter cases only those functions are investigated in which plastic strain appears to be of the first order. The predicted results of some basic tests are examined for several loading criteria.

Residual Stresses. F. B. Vazquez. (Tecnica Metalurgia, 1950, vol. 6, Aug., pp. 281–293). [In Spanish]. The author deals with the general conception of residual stresses and some definitions. The origin of residual stresses and methods of calculating these stresses are surveyed. An example is given of the calculation of residual stresses originating from thermal stresses. The effects of residual stresses from welding and from hardening are discussed.—R. S.

The Evaluation of Macroscopic Residual Stresses in Cylindrical Bars. H. Föppl. (Journal of The Iron and Steel Institute, 1951, vol. 168, May, pp. 15–23). The basic assumptions for the classification and calculation of residual stresses are discussed. Some recent advances in the theory of the straining of materials are considered which can be used in obtaining the limiting values of residual stresses at each local point in a body. A simplified idea is introduced to describe the plastic deformations which cause residual stresses. This includes an intermediate layer between the surface and the core in which a 'stress reversal' takes place. Theories of stress reversal are confirmed by results calculated from new equations. These results are compared with results calculated from Heyn's and Sachs' equations. It is shown that all the stresses can be calculated accurately, even if the strains are measured in only one direction. It was ascertained from the experiments that a mainly bi-axially stressed surface layer can behave independently of the tri-axially stressed core of the specimen.

Residual Grinding Stresses in Mild Steel. J. Frisch and E. G. Thomsen. (Transactions of the American Society of Mechanical Engineers 1951, vol. 73, Apr., pp. 337–346). A method for determining residual surface stresses is presented. For their determination, it is necessary to remove small layers from the part which has been bent by the residual stresses in the unrestrained state and to measure the resulting change in deflection and thickness of metal removed. Etching with a weak nitric acid and water solution was a satisfactory means of removing surface metal without introducing additional stresses. Mild-steel bars were ground with a medium-soft grinding wheel in a surface grinder. The depth of surface layer containing residual stresses extended to approximately 0·012 to 0·018 in. below the surface for grinding cuts ranging in depth from 0·0003 to 0·003 in. The thickness of the layer containing residual stresses increases with increasing depth of grind. The maximum residual stress occurs on the surface and, for all depths of grinds, was considerably below the yield point of the original material. The maximum surface stresses when grinding mild steel within the foregoing range of depth of cut decreases with increasing depth. It is believed that this phenomenon can be explained by the possible partial recrystallization of the surface grains because of the light surface temperatures obtained with heavy cuts.—D. H.

Effect of Internal Stresses on the Behaviour of Members in the Plastic Range. J. F. Baker and M. R. Horne. (Engineering, 1951, vol. 171, Feb. 23, pp. 212–213). The authors consider whether residual stresses due to welding may not invalidate the application of the simple plastic theory in which it is assumed that members are free from initial internal stresses. To illustrate the effect of residual stresses on the behaviour in bending of a beam the authors examine the case of a built-up **I**-beam to which is applied a continuously increasing bending moment. As long as conditions of instability do not arise, the existence of residual stresses due to welding has no effect on the value of the full plastic moment. The residual stresses, however, do lower the bending moment at which the relationship between moment of resistance and curvature becomes non-linear.—M. D. J. B.

A Theory of Deformation Textures in Metals. W. R. Hibbard, (Société Française de Métallurgie : Revue de Métallurgie Mémoires, 1951, vol. 48, Feb., pp. 131–134). A theory is suggested based on considerations of stable orientations of monocrystals and of slip and flow under the effect of a particular applied stress. The theory predicts the predominant textures found experimentally in metals, but does not account for the deviations from these ideal orientations found in pole figures.—A. G.

Internal Friction Measurement. A. S. Darling. (Metal Industry, 1951, vol. 78, Mar. 23, pp. 223–225 ; Apr. 6, pp. 271–273 ; Apr. 13, pp. 291, 292). The author reviews published literature relating to internal friction in metals, and indicates how its measurement offers a method for investigating charges in the structure of metals under the action of stress. In general, the graph of internal friction plotted against frequency of vibration will have a number of peaks, each peak being attributed to a characteristic time of relaxation. This relaxation is caused by some change in microstructure and the probable mechanism of the change can thus be deduced. Information about the mechanical properties of slip bands can be gained which would be impossible by any other method. At present, theory is much in advance of reliable experimental results, but if the experimental techniques can be improved they should occupy a field in metallurgical research comparable to that now held by X-ray diffraction methods. There are 40 references.—P. M. C.

Some Phenomena Associated with the Work-Hardening and Tempering of Steels. P. E. Brookes. (Metal Treatment and Drop Forging, 1951, vol. 18, Feb., pp. 75–85). Measurements of the residual stresses in cold-drawn steels have been made using the sensitive X-ray back-reflection technique. The results have shown that the stresses which exist in low-carbon steels are mainly of the long-range type, whereas this type of stress is of a secondary magnitude in pearlitic high-carbon steels. In the latter, a system of textural stresses is set up between the ferrite and cementite, which impedes the full development of the resistance to deformation which is typical of cold-worked ferrite. Release of these stresses on tempering at 150–350° C. is brought about by a yielding of the cementite, which in turn is accompanied by an increase in hardness due to the removal of the Bauschinger effect. There are 13 references.—P. M. C.

Hooke's Law, Is It a Limiting Law ? A. Jaquerod. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Feb., pp. 85–90). The bending vibration of thin strips of various steels and brasses is studied by means of a vibrograph. The oscillations are not isochronous as demanded by Hooke's Law, the period diminishing with amplitude. Even at very small amplitudes there is no indication that a limiting law is being approached.—A. G.

The Influence of Active Substances on the Surface of Metal Parts on Their Fatigue Limit. G. V. Karpenko. (Zavodskaya Laboratoriya : Hutnické Listy, 1951, vol. 6, Mar., p. 148). [In Czech]. The author criticizes the practice of fatigue testing in air applied to parts which are to operate in oil. Fatigue tests were made at 2840 cycles/min. on Kh40 steel (C 0·04%, Cr 0·95%, Ni 0·40% max.). The fatigue limits in castor oil were about 16% lower than in dry air, and the values for specimens in a 2% solution of iso-amyl-alcohol were about 44% lower than the corresponding values in dry air. Carbon steels were tested in dry air and iso-amylalcohol solutions at 10,000 cycles/min. The values in the latter were about 15% lower than in the former. The influence of the surface quality of the part and the concentration of the working medium were also examined. Ground surfaces are more sensitive to this effect than turned parts and heat-treated parts are more sensitive than those not heat-treated. Even very low concentrations of surface-active substances in lubricating oil cause a decrease in the fatigue limit of the lubricated part.—E. G.

The Fatigue Crack As a Stress-Raiser. A. J. Fenner, N. B. Owen, and C. E. Phillips. (National Physical Laboratory : Engineering, 1951, vol. 171, May 25, pp. 637–638). The authors describe the formation and propagation of cracks at low nominal stresses. The commonly held theory that a fatigue crack will inevitably develop at an increasing rate until failure of the section occurs, requires some revision. There is evidence that cracks may be present in parts submitted to fatigue for extremely lengthy periods. The authors show how, although it must not be assumed that a fatigue crack known to exist in a machine component can be regarded as harmless, it is nevertheless possible to initiate a fatigue crack which fails to develop beyond a certain point, though the cyclic conditions of loading remain unchanged.—M. D. J. B.

The Effect of Shot Peening, and Shot Peening and Stress Relief, on the Fatigue Properties of SAE 1080 Steel. N. B. Brown. (Canadian Mining and Metallurgical Bulletin, 1951, vol. 44, Mar., pp. 191–195). Smooth machined specimens of SAE 1080 steel were tested in air and water in R. R. Moore high-speed rotating bending machines in the following conditions : (*a*) Un-peened, (*b*) shot-peened, and (*c*) shot-peened and stress-relieved at 232° C. With normalized steel in air there was a 12% increase in fatigue limit after treatment (*c*) and a 5% increase after treatment (*b*) alone. With steel quenched and drawn, increases of 4·1% and 9·0% in fatigue limit were shown after surface treatments (*b*) and (*c*) respectively. In both cases a distinct increase in endurance life under water-corrosion conditions was observed after treatments (*b*) and (*c*).—T. E. D.

A Method of Fatigue Testing Drill Rods. T. W. Wlodek. (Canadian Mining and Metallurgical Bulletin, 1951, vol. 44, Mar., pp. 181–190). A simplified method of fatigue testing

full-sized, as-rolled, non-machined mining drill rods is described. A 10,000 in.-lb. Sonntag SF–10R rotating-beam fatigue machine was suitably modified for taking the drill rods. Three different lots of steel were tested and $S–N$ curves (stress against number of cycles on a log scale) under dry conditions were drawn. These curves permit the classification of drill rods on the basis of fatigue limit and endurance strength of the outside fibres of the metal, which depend to some extent on the effect of surface decarburization, surface imperfections, and surface treatments. The average slope of the $S–N$ curves in the damaging zone, which could be used as an evaluating factor for drill rods, and the fatigue limit in equal tension-compression rotating bending were determined for SAE 1080, chromium–molybdenum, and nickel–chromium–molybdenum steel mining drill rods.—T. E. D.

A Study of Fatigue in Metals by Means of X-Ray Strain Measurement. J. A. Bennett. (Journal of Research of the National Bureau of Standards, 1951, vol. 46, June, pp. 457–461). X-ray determinations of lattice strain were made on steel specimens under a series of static bending moments. These series of determinations were made on the specimens as normalized and after various amounts of fatigue stressing. The slope of the line relating the bending moment to the lattice strain was found to decrease with increasing numbers of cycles of alternating stress. However, the decrease was of approximately the same magnitude for specimens stressed above and below the fatigue limit, showing that the change was not associated with fatigue damage.

Theories on the Age-Hardening of Alloys. F. Rohner. (Berg- und Hüttenmännische Monatshefte der Montanistische Hochschule in Leoben, 1951, vol. 96, Feb., pp. 21–25). This is a review of the literature on theories of age-hardening. (40 references).—O. H. G.

Microcalorimetry and the Possibilities of Its Application in the Investigation of Metals and Alloys. O. Hajiček. (Hutnické Listy, 1951, vol. 6, Mar., pp. 111–118. [In Czech]. The development of microcalorimetry and microcalorimeters is reviewed. Although the main fields of application of microcalorimetry at present do not include metallurgy, it can be very useful for investigations of various phenomena in metals and alloys. Results of tests are given for three cases of application of this method to metallurgical investigations. The first concerns lead, the second aluminium, and the third the measurement of iron losses due to the action of a magnetic field of frequencies between 1000 and 10,000 cycles/sec.

Magnetic Analysis of Iron–Carbon Alloys—The Tempering of Martensite and Retained Austenite. J. Crangle and W. Sucksmith. (Journal of The Iron and Steel Institute, 1951, vol. 168, June, pp. 141–151). The observation of structure-insensitive magnetic properties, particularly magnetic saturation intensity and its variation with temperature, has been used to examine the phases involved when quenched pure iron–carbon alloys are reheated. Results indicate some magnetic properties of the phases, and their compositions. It is shown that during the first stage of the martensite breakdown a ferromagnetic phase different from cementite is precipitated: some of its magnetic properties are indicated. Retained austenite is found to change into the same state as does martensite. After heating to 300° C., cementite and another carbide with composition and magnetic properties similar to those of iron percarbide ($Fe_{20}C_9$), are found to be present.

Dye Penetrant Quickly Reveals Surface Flaws. A. Gilbert. (Iron Age, 1950, vol. 166, Nov. 16, pp. 91–92). This paper describes a dye-penetrant method of inspection for surface flaws. The process is completed in three steps: After cleaning the part the penetrant is applied, the excess is then washed off, and a developer applied. The special penetrant compound is a liquid having high capillarity and low surface tension in which is dissolved a brillant red dye.—A. M. F.

The Variation in Electrical Properties of Silicon–Iron Transformer Sheet—A Statistical Analysis of Data from a Single Cast. S. Rushton and D. R. G. Davies. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 247–261). This study of the variation in iron-loss values of sheets produced from a single cast of silicon–iron transformer sheet is based on 264 values from 11 ingots of the cast, and on iron-loss values of all the sheets produced from one particular ingot. The statistical technique of analysis of variance has been used to show the contributions to the total variation among these values due to differences between ingots, variation due to different positions in an ingot, and variation due to differences in the position of the sheet in the pack at the sheet-rolling stage. The effect of a second anneal has been studied, using the analysis of covariance technique. Causes of the variation in iron-losses are discussed.

Non-Destructive Methods of Testing and Their Application. L. van Ouwerkerk. (Teknisk Tidskrift, 1949, vol. 79, June 4, pp. 435–439). [In Swedish]. In Holland a central non-destructive testing organization has been introduced to serve the individual industries. An outline of available methods is given, including radiography, X-ray crytallography, electrical resistance measurements, liquid absorption methods, magnetic methods, and heat transference and supersonic methods.—B. S. E.

Nondestructive Testing of Engineering Materials and Parts. R. C. McMaster and S. A. Wenk. (Materials and Methods, 1951, vol. 33, Feb., pp. 81–96). The authors assemble the basic facts about all the available non-destructive testing methods. The following are described, and the capabilities and limitations of each are discussed: Penetrating radiations (X-rays, radium and cobalt 60); ultrasonic testing; magnetic particle methods; the use of penetrant dyes; and electro-magnetic-induction tests.—P. M. C.

Non-Destructive Testing of Materials. P. Olmer. (Métaux–Corrosion–Industries, 1951, vol. 26, Jan., pp. 20–21). An international colloquium on non-destructive testing of materials in which Belgian, British, French, and German representatives participated was held at Saarbrucken in December 1950. Testing by X-rays, gamma-rays, and with radioactive isotopes was discussed as well as the use of ultrasonics, magnetic, electrical, and other methods. A list of the authors and of the papers read is appended.—P. F.

Non-Destructive Testing of Adhesion Defects in Bi-Metals and Thin Sheet. J. Van Nieuwkoop. (Metalen, 1951, vol. 6, Apr., pp. 110–112). [In Dutch]. The principles of an electric resistance method tried by Metropolitan Vickers Electrical Co., Ltd., and further developed by the X-Ray Technical Department at Rotterdam are described. Possibilities and limitations of this apparatus are discussed and the electrical circuit is illustrated.—R. S.

The Scope of X-Ray Analysis as a Means for Non-Destructive Testing. A. Guinier. (Métaux–Corrosion–Industries, 1951, vol. 26, Mar., pp. 131–134). The sensitivity and speed of determining X-ray diffraction lines of materials can be considerably improved by using Geiger-Müller counters instead of photographic plates. If this method is used in conjunction with the filing-card or punched-hole card index of X-ray diffraction lines a useful method for testing the composition of materials results. Examples are given.—P. F.

Radiography of Welded Joints for Power Plants. J. H. Lawson. (Australian Institute of Metals: Australasian Engineer, 1951, Feb. 7, pp. 78–82). The author describes a mobile X-ray laboratory for the examination of pipe welds in the field. The unit contains its own dark room and the self-powered X-ray tube is capable of a continuous output of 300 kV. at 6 milliamp. Alternative procedures for making an examination are outlined, and the principal types of fault and their identification are discussed. Finally, hints are given for the most suitable types of film, intensifying screen, and cassette.—P. M. C.

Non-Destructive Testing of Steels. B. H. d'Entremont. (Métallurgie, 1951, vol. 83, Feb., pp. 97–105; Mar., pp. 161–167). The author describes the Brinell, thermoelastic, spark, colorimetric, and electronic tests. A table is given for internal and external defects, showing the most suitable methods for non-destructive testing for each type of defect and also methods of preventing them. Crack-detection methods include the use of alcohol and fluorescent liquid (Zyglo method). In the second part, magnetoscopic, ultrasonic, and radiographic methods are discussed, with a final note on the use of such testing methods as are based on the elastic properties, including the Le Rolland rigidometer, stress coat method, and strain gauges.—R. S.

The Use of Liquids in Non-Destructive Flaw-Testing. H. de Leiris. (International Colloquium on Non-Destructive Testing of Materials, Saarbrücken, 1950: Metaux–Corrosion–Industries, 1951, vol. 26, Jan., pp. 22–28). The application of highly coloured organic liquids for the detection of flaws and fatigue cracks is discussed. The method is said to compare favourably with the most modern developments in non-

destructive testing. It can be made highly sensitive by employing fluorescent liquids which are as efficient for most materials as the magnetic-powder method used for ferrous metals. The wetting abilities of liquids of varying composition are shown by means of photographs of the spread of drops.—P. F.

Some Sources of Error in Ultrasonic Testing of Pieces of Metal. P. Bastien. (Métaux–Corrosion–Industries, 1951, vol. 26, Mar., pp. 135–141). Sources of error in non-destructive testing by ultrasonic methods are examined.—P. F.

The Non-Destructive Testing of Materials, Particularly Machinery Parts, by Ultrasonics. Metalen, 1951, vol. 6, May, pp. 165–172). [In Dutch]. Some tests with a Hughes and Kelvin machine at Stork & Co., Hengelo, are described. Interpretation of results was confirmed by macro- and micro-examination.—R. S.

Practical Testing of Materials by Means of Ultrasonics. H. Krautkrämer and J. Krautkrämer. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, May 1, pp. 349–362). Apart from a brief review of the transmission and resonance methods the paper is principally concerned with the impulse-reflection methods. The principles of this are first explained. Detailed accounts of the use of a German instrument designed by the authors are given. This includes the use of thrust waves as devised by F. A. Firestone (*see* Journ. I. and S.I., 1949, vol. 162, June, p. 242).—J. G. W.

The Use of Ultrasonics in the Inspection of Materials. (Métallurgie, 1951, vol. 83, Jan., pp. 39–42). The properties of ultrasonic waves are described. Methods of measuring intensity and the echo method are mentioned.—R. S.

Industrial Applications of Radioisotopes. P. C. Aebersold. (Non-destructive Testing, 1950–51, vol. 9, Winter Issue, pp. 10–16). Radioisotopes have been established as having greater sensitivity, specificity, and versatility than any other research and engineering tool now known. The author outlines the three different analytical techniques—tracer analysis, isotope dilution analysis, and activation analysis. Applications of radioisotopes as sources of radiation for radiographic flaw detection and thickness gauging are described. The tremendous scope for tracers in investigations of physical and physical-chemical transfer of materials, is pointed out with examples. These include : The solid diffusion of metals, the migration of metallic ions into insulating compounds, the transfer of materials during friction wear, physical-chemical aspects of detergency, the mechanisms of chemical reactions, etc.—P. M. C.

Apply Radioisotope Cobalt 60 to Radiography of Castings. H. R. Isenburger. (American Foundryman, 1950, vol 18., July, pp. 48–49). An exposure chart for the gamma radiography of steel castings is presented in which radium equivalent in milligram-hours is plotted against steel thickness in inches. This permits the chart to be used for testing castings with radium or cobalt 60. Radiation source to film distances and types of film, with or without the use of a screen, are tabulated, and from these are derived the exposure times in milligram-hours. The chart is discussed and temperature corrections for exposure times are given.—E. J. D. S.

High-Temperatures Problems in Aircraft Jet Engines and Turbo-Superchargers. R. B. Johnson. (Metal Progess, 1951, vol. 59, Apr., pp. 503–510). This article deals with the problem of obtaining a useful life for parts of engines running at temperatures of the order of 500° C. It has been found that the primary solution is careful design. The requirements of various parts are considered in detail, and summarized in a table, giving the metallurgical desiderata and the required manufacturing characteristics.—E. T. L.

Bonding of Titanium Carbide with Metal. W. J. Engel. (National Advisory Committee for Aeronautics, Technical Note No. 2187 : Metal Progress, 1951, vol. 59, May, pp. 664–667). Titanium carbide was studied as a possible material for gas turbines. This paper reports experiments on the penetration of molten metals into carbide bricks, as shown by the use of a microscope and hardness determinations. Only nickel, cobalt, chromium, and silicon bonded satisfactorily, the first two being best.—E. T. L.

The Significance of the Hydrogen Content of Steel Welds. C. G. Keel. (Berg- und Hüttenmännische Monatshefte der Montanistische Hochschule in Leoben, 1950, vol. 95, Dec., pp. 318–325). This is a review of the literature.—U. E.

The Physics of Metals—Diffusion and Interaction of Impurities and Defects of Structure in Metals. C. Crussard. (Métaux et Corrosion, 1950, vol. 25, Sept., pp. 203–226). Defects which disturb the reticular regularity of metallic crystals are described. Diffusion of slip occurs by means of three mechanisms : (1) Formation of gaps in the network near to the line of slip and the diffusion of these gaps (rather unlikely) ; (2) absorption of dislocations attracted to the slip as a result of elastic interaction (very probable but slow) ; and (3) slight oscillations of the line of slip according to a polygonal contour. A theory is evolved of the interaction between a field of stress and a local defect. The formulæ evolved permit the calculation of the interactions between : Two identical foreign atoms ; two different foreign atoms ; an atom and a gap ; two or more gaps ; and slip and impurities or gaps. The application of these theories to the mechanical properties of mild steels, and to precipitations are studied.—R. S.

The Physics of Metals—The Part Played by Diffusion in the Surface Oxidation of Metals. J. Bénard. (Métaux et Corrosion, 1950, vol. 25, Oct., pp. 241–247). According to Pilling and Bedworth in 1923, metals fall into two classes from the point of view of oxidation : (*a*) Metals whose volume is greater than that of the oxide which they produce (Li, Na, K, Mg, Ca, St, and Ba) ; and (*b*) metals whose volume is less than that of the oxide produced (Al, Cu, Zn, Fe, Co, Ni, Mn, and Cr). This classification is still substantially correct. The article discusses the kinetics of oxidation, the mechanism of diffusion in oxidation films, their microscopic structure, and the influence of the nature of the metal–oxide interface on the rate of diffusion.—R. S.

The Diffusion of Gases in Metals—The Iron–Hydrogen System. P. Bastien. (Métaux and Corrosion, 1950, vol. 25, Oct., pp. 248–261.) The article deals with the adsorption of a gas by a metal and in the hydrogen–iron system. The second part deals with the diffusion of a gas in a metal and the permeability of iron to hydrogen in gaseous and aqueous media. The third part discusses the solubility of gases in metals.—R. S.

Experimental Studies of the Phenomena of Diffusion. A. Guinier. (Métaux et Corrosion, 1950, vol. 25, Sept., pp. 227–236). Experiments involving the measurement of the coefficient of diffusion are difficult and not very precise but they enable Fick's equations to be verified in various cases of diffusion of gas or metals in a metal. The differences between the values found in various experiments can be explained by the fact that the rate of diffusion is determined by the value of free energy of the systems evolving. The degree of perfection of the crystal network is a very important factor in the kinetics of reactions in the solid state.—R. S.

Temperature Coefficients and the Processes of Adsorption of Gases on Metals. A. G. Nasini and G. Saini. (La Chimica e L'Industria, 1951, vol. 33, Feb., pp. 67–70). [In Italian]. A brief critical examination is made of the literature dealing with temperature coefficients of gases on metals with particular reference to the processes of absorption and to the, now classical, experiments of Roberts on 'cleaned' tungsten filaments. Results obtained by a new technique are given. This method is claimed to be more easily applicable than that followed by Roberts and is not, moreover, limited to gases which are difficult to compress. The temperature coefficient method applied to metallic filaments enables surfaces to be kept 'clean' for only a few minutes ; experiments are therefore limited to the study of short-lived phenomena. New equipment is described permitting direct manometric measurements to be made on perfectly 'clean' metallic filaments. The principal characteristics of the equipment are : A surface about 100 times larger than that used by Roberts ; the small size of the apparatus ; the use of a Rostagni manometer with glass filament permitting rapid and accurate pressure measurements avoiding the presence of metallic surfaces and vapours. The equipment may be used also with gases which are difficult to condense.—M. D. J. B.

Influence of Various Alloying Elements on the Technological Properties of Cast Iron, Particularly on Thermal Stability. H. Timmerbeil. (Giesserei, 1951, vol. 38, Jan. 25, pp. 25–29). The paper is concerned with cast iron for air-heater tubes such as are used in preheaters for hot-blast cupolas. After reviewing some non-scaling cast irons, the author reports research by the Verein Deutscher Ingenieure Committee on 'M.T.C. resistant cast iron.' In all, 3038 specimens prepared in 49 casts were tested for cold and hot tensile strength, cold and

hot bending strength, growth, scaling at 700°, 800°, 900°, and 1000° C. in air, and for Vickers hardness, in addition to the usual tests. The alloying additions consisted of 1·5–5·5% Si in combination with about 4% Al and 2% C, 2–6% Al in combination with about 5·5% Si and 2% C, 3–6% Si in combination with 6% Al and 2·5% C, 2–4% Si with 1·3% Cr and 3% C, and others not described in the paper. It was concluded that the cast 1·85% C, 5·35% Si, 0·54% Mn, 0·57% P and 4% Al was more stable in a test consisting of soaking for 100 hr. at 1000° C. than the cast 3·04% C, 3·74% Si, and 1·34% Cr tested for the same time at 900° C. The strength of the former was sufficient for the application in view; its ductility was excellent.—J. G. W.

Metallurgy behind the Decimal Point. E. E. Schumacher. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1097–1110; Journal of Metals, 1950, Sept.). The author discusses the critical effect on the properties of metals and alloys which may be exerted by minute additions of certain elements. As examples, he cites the pronounced effect of small quantities of silver, calcium, and nickel on the strength properties of lead; and the effect on the magnetc properties of iron of small changes in carbon, sulphur, oxygen, and nitrogen contents.—G. F.

The Role of Alloying Elements in Steel. B. H. d'Entremont. (Métallurgie, 1950, vol. 82, Nov., pp. 859–867; Dec., pp. 959–965). The general behaviour of the elements in the iron and steel making processes is described. Their effects on steel quality during heat-treatment are outlined and their influence on austenite, hardenability, ferrite, resistance to oxidation, machinability, and other physical and mechanical properties are summarized.—R. S.

Effect of Initial Heating Temperature on the Mechanical Properties of Ni–Cr–Mo Steels. J. A. Wheeler, V. Kondic, and T. Ko. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 301–308). The effect of high austenitizing temperature on the tensile properties of air-quenched Ni–Cr–Mo steels has been studied. Increasing the austenitizing temperature causes a progressive lowering of the ductility when the steel is fully martensitic after cooling. Heating to high temperatures prompts the formation of intermediate transformation products during subsequent cooling, with a consequent slight increase in the ductility and a decrease in the tensile strength. In one steel, precipitation of sulphide in a Widmanstätten pattern after being heated above 1350° C. causes pronounced loss of maximum stress and fracturing along $\{100\}$ planes, on which the inclusions were precipitated.

Nickel–Molybdenum Steel Used in the Manufacture of Tapered Roller Bearings. J. H. Evans. (Alloy Metals Review, 1951, vol. 8, Apr., pp. 2–7). The author discusses the metallurgical inspection procedure, applied by British Timken, Ltd., with particular attention to factors influencing the machinability and hardenability of the steel. The most popular analysis is SAE 4620 (En 34 1·65–2·0% Ni, 0·20–0·30% Mo) or a modification of this with controlled grain size to ensure uniform hardenability of case and core. A graph of minimum and maximum Jominy end-quench hardenability, and a table of mechanical properties, are presented.—E. C. S.

Modern Trends in Airframe Materials. L. Schapiro. (Metal Progress, 1951, vol. 59, Apr., pp. 511–515). Recent progress in increasing the pay-load/airframe-weight ratio is linked with the use of better aluminium alloys, although these were less easy to heat-treat. There have been developed even more recently in America three steels, Hy-Tuf, B-514, and Cr–Ni–Mo–V type 2, with comparable strength/weight ratios, and with good ductility and impact resistance. It is pointed out that in the future, higher speeds will lead to skin-friction of the air on the airframe which will heat the latter, so lessening its strength. Possible lines of future development involve the use of titanium or magnesium alloys.—E. T. L.

Form Stability and Material Tests of Two Welded Cylindrical Pressure Vessels Made of Age-Hardening Steel Plates. H. Biegler. (Die Technik, 1951, vol. 6, Apr., pp. 155–162). From tests to destruction of the vessels and material tests, including ultimate tensile stress, elastic limit, elongation, and reduction of area at fracture, it was concluded that the fracture strength of the containers could not have been predicted from the material tests. Further tests are to be performed, but in the meantime it is concluded that the compression notch bend test, though more suitable than the impact test, cannot by itself be relied upon for it does not take account of the strains present in the manufactured vessel.—J. G. W.

Structure, Hardness, and Machinability of Iron–Carbon–Silicon Alloys. R. Mitsche and W. Schreiber. (Neue Giesserei, 1950, vol. 37, Nov. 2, pp. 485–488). The authors investigated the relation between machinability, structure, and hardness of high-silicon cast irons. They found that, contrary to statements in the literature, some alloys with more than 7% of silicon can still be machined. Provided the carbon content is high, cast irons with as much as 10% of silicon are quite readily planed and bored. This is probably due to the presence of graphite.—J. G. W.

Flat Rolled Stainless Steel. J. L. Cotsworth. (Canadian Metals, 1951, vol. 14, Feb., pp. 10–13, 45–46). An outline is given of types, sizes, and standards of stainless steel commonly available in America. Special manufacturing techniques are discussed in brief, concerning melting, hot rolling, annealing, pickling, cold rolling, and polishing. There is a short list of proposed applications for special types of stainless steel.—E. C.

The Need for More Suitable Steel in Shipbuilding. P. Stenberg. (Teknisk Tidskrift, 1949, vol. 79, No. 17, pp. 301–304). [In Swedish]. The reports of the American Maritime Commission on the failure of welded ships are reviewed with reference to materials and materials testing. The American Bureau of Shipping specifications for ship steels and the Schnadt tests still leave more reliable methods to clarify notch sensitivity to be desired.—B. S. E.

Multiply Spring Life without Changing Design. C. W. Oicles and F. K. Landecker. (Iron Age, vol. 166, Dec. 21, pp. 80–82). An increase in the life of a cold-formed 'C' spring used in a drill pipe tong, from an average of 1700 cycles to over 20,000 cycles has been achieved by a change from SAE 1095 to 6150 spring steel, the use of a martempering heat-treatment, and a peening operation.—A. M. F.

Laminated Torsion Bars. (Engineer, 1951, vol. 191, Mar. 16, pp. 349–350). This article describes the design and application of laminated torsion bars developed and fabricated by Geo. Salter and Co., Ltd., West Bromwich. After a brief discussion on the problems of road vehicles' front wheel suspension, the advantages of the torsion bar over the helical coil spring are described.—M. D. J. B.

New Notes on High-Strength Heat-Treated Steels. G. Sachs, G. S. Sangdahl, and W. F. Brown. (Iron Age, 1950, vol. 166, Nov. 23, pp. 59–63; Nov. 30, pp. 76–80). The work reported in this paper is devoted to distinguishing between different low-alloy steel compositions that were heat-treated to a tensile strength above 175,000 lb./sq. in. or hardness between 350 and 500 Brinell. Conventional tensile tests indicate practically similar mechanical properties, but a special concentric notched-bar tensile test shows that the properties of such steels are greatly dependent upon composition, the method of steelmaking, and hardenability. It is shown that the effect of 2% Mn as compared with 3·5% Ni or 1% Cr in 0·4% carbon steel is to decrease suddenly the notch strength and ductility if the hardness exceeds 450 Brinell. The effects of quenching media on notch properties have also been closely investigated.—A. M. F.

Two Steels Make Our Plastic Molds. R. W. Brown. (Machinist, 1951, vol. 95, Feb. 17, pp. 232–233). Tests at Westinghouse Electric Corp. have cut types of mould-steel down to two, the analyses of which are (1) 0·32–0·38% C, 0·45–0·60% Mn, 0·025% max. P, 0·025% max. S, 0·20–0·35% Si, 3·25–3·75% Ni, 1·40–1·75% Cr, 0·25% Mo; and (2) 0·07% max. C, 0·20–0·40% Mn, 0·40–0·60% Mo, 4·5–5·0% Cr. By the exclusive use of these two air-hardening steels, moulds are improved, heat-treating problems simplified, and costs reduced.—E. C. S.

The Effects of Low Temperatures (below Freezing Point) on the Mechanical Properties and Working of Austenitic Stainless Steels. N. V. Krivobok. (Bulletin de le Société Royale Belge des Ingenieurs et des Industriels, 1951, Feb., pp. 14–32). A survey is made of the information available on the effects of low temperatures on stainless steels, and the results given of further experimental work in this field. Austenitic stainless steels were exposed to a temperature of −196° C. during and after working and then tested under various temperature conditions. It was found that such steels worked at low temperatures showed an increase in ductility over the same steels worked conventionally.—J. J.

High Resistance and High Quality Pig Irons. M. Noris. (Rivista di Meccanica, 1950, vol. 1, Sept. 1, pp. 13–16). [In Italian]. A classification is given of the mechanical characteristics of high-grade, wear-resisting irons used in machine parts. The practical possibilities attainable in modern foundries are described and possible future developments discussed.—M. D. J. B.

The Industrial Status of Ductile Iron. A. P. Gagnebin. (Mechanical Engineering, 1951, vol. 73, Feb., pp. 101–108). The paper is a summary of the achievements to date in the field of ductile iron. Representative mechanical properties of commercial heats of the iron are given and discussed. Typical compositions used and the effect of alloying elements are noted. The reliability of the process of manufacture is stressed. Ductile iron combines the fluidity and cast ability of cast iron with properties resembling steel, and this is its outstanding feature. Stiffness, strength and toughness, wear, fatigue and heat-resistance, and machinability are discussed with reference to typical castings.—D. H.

Bainitic or Acicular Castings. M. T. Varela. (Tecnica Metalurgia, 1950, vol. 6, Aug., pp. 294–299). [In Spanish]. The main properties of bainitic or acicular castings are described. The definite methods of determining the **S**-curve are surveyed. The influence of nickel and molybdenum is explained. Methods of manufacturing and heat-treating this type of casting are described.—R. S.

New High-Duty Cast Irons. P. O. Björkman. (Tekinsk Tidskrift, 1949, vol. 79, Oct. 15, pp. 741–746). [In Swedish]. The British and American development of acicular and nodular cast-iron production is reported and comparisons of properties and merits are made. The theories of nodular graphite formation are mentioned.—B. S. E.

Contribution to the Study of High-Phosphorus Cast Iron. J. Galey. (Fonderie, 1951, Jan., pp. 2313–2328). The cast irons studied were made from low-carbon hematite and a 25% ferrophosphorus with addition of silicon. The Fe–P and the Fe–C–P diagrams are presented. Mechanical properties including static bend tests, shear strength, modulus of elasticity and corrosion properties are discussed. Whilst the mechanical properties are mediocre, possibilities in the sphere of resistance to acids are hopeful.—R. S.

METALLOGRAPHY

The Application and Scope of the Stamped Replica Process in the Electron Micrography of Metal Surfaces. Johanna Hunger. (Zeitschrift für Metallkunde, 1951, vol. 42, Mar., pp. 65–72). Electropolished foils of 99·99% aluminium, approximately 0·1 mm. thick are pressed on to the metal to be examined, to produce replicas. The pressure is applied to the cushioned foil and specimen by two plane tool-steel flats inserted into a tension-compression machine. In the case of a steel having a fine pearlitic structure a stress of 20 tons/sq. in. was sufficient to give a replica with a resolution certainly not inferior to that of the electron microscope (about 8 millimicrons). Illustrations are given showing that these replicas are at least as good as standard lacquer ones. With a compression speed of 0·8 in./min., followed by 30 sec. under full load, best results were obtained with martensite, pearlite, tool steels, nitrided steels, and high-speed steels as well as with softer steels. Ferrous metals with graphitic inclusions were not examined, but are likely to be unsuitable. Good replicas were obtained from hard chromium surfaces, while soft metals such as alloys of zinc, magnesium, and aluminium could not be employed. As a general rule the method is applicable if the specimen to be examined, or its softest component, is harder than about 150 Brinell. The thin oxide film on the aluminium foil prevents it from sticking to the surface of the metal, but does not impair the resolution. Replicas of the surface of a softer metal can occasionally be obtained by cooling the metal to a low temperature and thus hardening it sufficiently to withstand the comparatively high pressures applied in the process.—P. F.

Phase-Contrast Microscopy in the Study of Metal Surfaces. D. McLean. (Metal Treatment and Drop Forging, 1951, vol. 18, Feb., pp. 51–62). The phase-contrast microscope shows up differences in surface level, as distinct from differences in reflectivity or colour, and is sensitive to approximately 50Å. The optical train of the incident-light phase-contrast microscope is described and illustrated, and vector diagrams are used to illustrate phase-contrast image formation. The application of this technique to the study of metals is described and illustrated by many micrographs. Polishing and etching techniques are discussed.—P. M. C.

Micropol and Disa-Electropol—Two Quick Metallographic Polishers. E. Knuth-Winterfeldt. (Transactions of the Instruments and Measurements Conference, Stockholm, 1949, pp. 223–226). Two commercially available Danish electropolishers are described. The Micropol is suitable for non-destructive purposes. It polishes an area of only 1 sq. mm. approximately, lying under the tip of the burette which holds the electrolyte. The liquid is in contact with the specimen at this point only. In the Electropol the specimen, in the form of a flat, is pressed by the spring-loaded anode against the top of the perforated tank holding the electrolyte. The specimen is polished over the area covering the circular perforation. The electrolyte is kept in motion by a small pump which pumps it from the tank to the specimen, whence it flows back into the container. With perchloric acid and ethyl alcohol as electrolyte, polishing takes from $\frac{1}{2}$–4 sec.—P. F.

The Use of the Electron-Diffraction Method for the Examination of Metal Surfaces. J. Piaskowski. (Hutnik, 1951, vol. 18, Apr., pp. 137–144). [In Polish]. Fundamental principles and apparatus for electron diffraction and the preparation of metal surfaces for examination are described. A survey of some investigations of metallic surfaces and conclusions concerning the formation of oxide layers are given. The influences of surface tension and diffusion in this process are discussed.—V. G.

Scale for Quantitative Evaluation of Crystalline Structures. S. A. Saltykov. (Zavodskaya Laboratoriya : Hutnické Listy, 1951, vol. 6, Apr., p. 195). [In Czech]. After criticizing the A.S.T.M. method of evaluating grain size the author describes his new method which is based on determining the total surface of the grain boundaries (in sq. min./cu. mm. of the metal) by comparison of the grain as seen under the microscope with ' standard ' scales.

Spectral Control of Thermal Treatment. J. M. L. de Azcona. (Memoires du Centre National de Recherches Métallurgiques, 1950, Dec., pp. 45–55). The relative intensities of the spectral rays of the constituent elements of an alloy vary with the physicochemical states of those elements. In this work, spectral measurements are carried out at elevated temperatures. The apparatus is described. If values of ΔD (difference in photographic density) for the elements contained in an alloy are plotted as a function of temperature, the physicochemical states of those elements can be followed. Similarly, the existence of intermetallic compounds can be examined. Thus by means of thermospectral analysis the equilibrium diagram of an alloy can be constructed. In addition, the formation of unstable phases is made apparent, and other properties such as ageing can be investigated. The materials examined included technical aluminium (impurities, magnesium, copper, iron, and silicon), Duralumin and Superduralumin (Al/Mg and manganese, iron, silicon, and copper), carbon steels, cast-iron, bronzes, and aluminium bronzes. T. E. D.

Some New Techniques in the Application of X-Rays to Metallography. A. Guinier. (Transactions of the Instruments and Measurements Conference, Stockholm, 1949, pp. 60–64). The more recent methods of X-ray crystallography such as the use of fine-focus tubes, ' white ' radiation and crystal monochromators are discussed with reference to the particular fields of the study of the crystal structure of metals in which their use has facilitated a more detailed and finer analysis. Work on steels should derive great benefits from these developments, though the low proportion of carbon in iron allows one to foresee even then considerable experimental difficulties.—P. F.

Decomposition of Remanent Austenite at Low (Sub-Zero) Temperatures. G. A. Oding. (Zavodskaya Laboratoriya : Hutnické Listy, 1951, vol. 6, Mar., p. 143. [In Czech]. The investigations were carried out by a differential dilatometer on steel specimens 4·5 mm. in dia. and 130 mm. long, which were heated to a suitable temperature and oil-quenched. The cooling speed in the dilatometer was 0·5 to 1·5° C./min. The materials used were : Chromium, chromium–tungsten, and chromium–silicon steels. The dilatometric curves show that when cooling at 0·5 to 1° C./min., hardened U12A steel shows a sudden noticeable elongation at a temperature of about −48° C. and the elongation continues during cooling to lower temperatures and stops suddenly at −116·5° C.

This elongation is due to transformation of residual austenite into martensite, and it can be concluded that some austenite remains and does not transform.—E. G.

The Importance of Silicon in Niobium-Bearing Steels and Alloys. H. J. Goldschmidt. (Metallurgia, 1951, vol. 43, Apr., pp. 157–160). A ternary iron–niobium silicide, with an approximate formula $Fe_4Nb_2Si_2$ has been found by X-ray analysis in extracts from niobium-bearing austenitic heat-resisting steels and in silicon-rich ferroniobium. Hence one can derive a tentative Fe–Nb–Si diagram. Silicon acts like carbon in heat-resisting steels, though the silicide- and carbide-forming tendencies are competitive. The Nb/Si ratio for instance, and the heat-treatment affect the formation or elimination of silicide.—E. T. L.

CORROSION

Corrosion Due to Tuberculation in Water Systems. I—The Effect of Calgon on the Potential of Iron Electrodes in Differential Aeration Cells with Running Tap Water. II—The Effect of Calgon on the Potential of Zinc and Copper Electrodes in Differential Aeration Cells with Running Tap Water. J. L. Mansa and W. Szybalski. (Acta Chimica Scandinavica, 1950, vol. 4, pp. 1275–1299). An attempt is made to show how Calgon interferes with the mechanism of corrosion due to tuberculation in water pipes. The influence of calgon on the potentials of the electrodes in a D-A-cell in running water is studied. Calgon decreases the potential of the cathode by the formation of an adsorption layer on its surface, which inhibits the access of oxygen to the iron surface with a consequent decrease in its passivating action. The potential of the anode rises because of interference with the anodic depletion of oxygen. Both these effects cause the decrease of the potential difference and of the corrosion current, which is also caused by the increase of the internal resistance of the cell due to the formation of protective layers of low conductivity. Corrosion of zinc under similar conditions, and its suppression with Calgon can be explained in the same way. Tuberculation and pitting in galvanized iron pipes are caused by zinc becoming cathodic against iron in the D-A-cell where the zinc surface is exposed to an aerated water stream and the iron is in stagnant water. Some other aspects of D-A-cells with zinc, iron, and copper electrodes are discussed.—T. E. D.

Coal-Ash Corrosion of Metals at Elevated Temperatures. C. T. Evans, jun. (Symposium on Corrosion of Materials at Elevated Temperatures, June, 1950 : A.S.T.M. Special Technical Publication No. 108, pp. 3–10). *See* Journ. I. and S.I., 1950, vol. 166, Dec., p. 387.

Corrosion-Fatigue of Metals : A Critical Survey. A. J. Gould. (Iron and Steel, 1951, vol. 24, Jan., pp. 7–10). The author discusses the phenomenon of corrosion-fatigue and considers its characteristics and the individual factors affecting its occurrence. Methods of testing the behaviour of metals under corrosion-fatigue conditions are briefly mentioned, and factors which contribute to reducing its severity are given. Previous work has shown that the phenomenon resembles stressless corrosion ; the amount of metal actually combining by virtue of the corrosive action is very small. The action is insidious because as it advances it creates very fine fissures. G. F.

Some Metallurgical Factors Affecting Corrosion. K. G. Lewis. (Journal of the West of Scotland Iron and Steel Institute, 1945–46, vol. 53, pp. 55–91). The characteristics of the oxide film are first discussed with an account of the methods used to isolate it. Corrosion is classified into drop corrosion (*e.g.*, in the atmosphere), underground corrosion, immersion corrosion—partial (water-line type) and complete acid corrosion, intercrystalline attack, and corrosion fatigue. Each type is considered in turn with emphasis on the first and last. The effects of foreign bodies, including inclusions and external particles, are discussed, together with the influence of constituents in the metal. The effect of marine and industrial atmospheres is reviewed, including results from corrosion tests at Blackpool and Manchester, the extent of corrosion being evaluated by the loss in mechanical properties of the sheet specimens. Pitting occurs to a lesser extent on copper-bearing than on plain carbon steels. Intercrystalline attack of aluminium alloys and 18/8 austenitic chromium–nickel steels is described, and an example of corrosion cracking in hollow forged containers is given. A comprehensive bibliography is included.—P. C. P.

ANALYSIS

Some Considerations on Electrometric Titrations. G. Duyckaerts. (Analytica Chimica Acta, 1951, vol. 4, June, pp. 233–237). [In French]. Electrometric titration methods are classified, with special reference to the potentiometric method at constant polarization. This is applied to the titration of Mn^{+2} by $KMnO_4$ in a pyrophosphoric medium (*p*H 7·8). By positive or negative polarization, the jump in potential at the end point is increased. An error in the end point is also produced, its magnitude rising according to the intensity of the polarization current.—T. E. D.

On the Accuracy of Zimmermann's Method of Determining Sulphur. W. Kirsten and C. Carstens. (Analytica Chimica Acta 1951, vol. 5, June, pp. 272–276). [In German]. The accuracy of this method was found to be lower than it has often been stated. The errors occur in the decomposition of the sample. In a recent modification by Zimmermann, the error is approximately compensated by the use of a titration procedure which gives too high results.—T. E. D.

The Detection of Phosphate with Molybdate Reagent and Its Behaviour in Qualitative Analysis. E. van Dalen and G. de Vries. (Analytica Chimica Acta, 1951, vol. 5, June, pp. 238–244). [In German]. The sensitivity of the detection of phosphate ion in nitric acid solution by an ammonium molybdate reagent containing ammonium nitrate is 1 : 50,000. The test may be made in the presence of silicic acid. Methods for the elimination of interfering ions are indicated.—T. E. D.

Separation of Iron, Aluminium and Titanium. H. N. Ray. (Journal of the Indian Chemical Society, 1951, vol. 28, Mar., pp. 150–154). Hydrogen peroxide is added to the acidified solution of iron, aluminium, and titanium, pertitanic acid being formed from the titanium. The addition of an excess of sodium carbonate solution containing sodium hydroxide precipitates the iron but retains the aluminium and titanium in solution. After filtration, the pertitanate is hydrolysed by boiling and comes down quantitatively as a curdy white precipitate, leaving the aluminium in solution.—T. E. D.

Mercurous Nitrate as a Reductimetric Reagent. I. Stoichiometry of the Reaction. II. The Interference of the More Common Cations and Anions in the Determination of Iron. R. Belcher and T. S. West. (Analytica Chimica Acta, 1951, vol. 5, June, pp. 260–271). The reaction between an acid solution of mercurous nitrate and ferric iron in the presence of excess of thiocyanate ions is stoichiometric over the range studied (3·0–300 mg. of iron). Ions capable of oxidizing ferrous iron cause interference. Copper and thallium must be completely absent, and ions which give coloured products with thiocyanate ions, *e.g.*, molybdenum. The interference of certain other anions and cations can sometimes be eliminated.—T. E. D.

INDUSTRIAL USES AND APPLICATIONS

Cast Irons for Glass Moulds. J. Guillamon. (Fonderie, 1951, Feb., pp. 2373–2374). Where ordinary cast iron is used for glass moulds, a fine grain which does not preclude good machinability, is aimed at. A typical composition is: C 3·4–3·6%, Mn 0·60–0·80%, Si 2·6–2·4%, S 0·08–0·12%, P 0·5% max. Alloy cast irons include the 35% Ni austenitic and Ni–Cr–Mo types.—R. S.

Possible Applications of Copper-Bearing Steels. E. H. Schultz and H. Bühler. (Métaux et Industries, 1950, No. 6, pp. 144–146). The high corrosion resistance of low-alloy copper-bearing steels, particularly when coated, is discussed with reference to a number of applications in large buildings and halls carried out by German firms. A steel of about 35 tons/sq. in. ultimate tensile strength, (0·12% C, 0·24% Si, 0·74% Mn, 0·022% S, 0·022% P, 0·43% Cr, 0·81% Cu) used in most of these cases gave very good results and a 14–17% saving in weight was achieved. The steel is easy to weld.—P. F.

The Use of Steel Supports in Mining Practice. K. Gross. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1951, vol. 96, Mar., pp. 42–47). Methods of using both rigid and flexible steel supports in mines are briefly described. An equation is proposed for calculating the relative cost of alternative methods of construction. A suitable mobile electric-hydraulic press for reconditioning steel supports is described.—O. H. G.

Precision Steel Tubes; Some Industrial Applications of Small-Diameter Bores. (Iron and Steel, 1950, vol. 23, Dec., pp. 501–503). A brief account is given of the rapidly increasing use of high-precision small-diameter tubing for scientific instruments and apparatus. This tubing falls broadly under six headings: (1) Bourdon tubing, (2) capillary tubing, (3) special process, high-pressure tubing, (4) pointer tubing, (5) multi-bore tubing, and (6) composite tubing. Some of its notable applications are given, and the materials used and accuracy attained are indicated.—G. F.

Development in the Use of Steel for Underground Support. F. J. Haller. (Mining Engineering, 1950, vol. 187, Apr., pp. 475–478). Experiences in the development of over five miles of permanent underground openings and haulage drifts are described, showing structural steel sets to be permanent, safer, and, in the long run, cheaper than treated or untreated timber supports. Excavation is reduced, and costs of installation, transportation, and handling are less.—E. C.

HISTORICAL

The Steel Armour of Edward the Black Prince. (Steel News, 1951, vol. 2, June, p. 16). The helm and crest of the Black Prince, in very good condition after 600 years' exposure to atmospheric corrosion, are described.—T. E. D.

Early Days of Iron and Steel in North America. Q. Bent. (Newcomen Society: Blast Furnace and Steel Plant, 1951, vol. 39, Mar., pp. 351–353). Iron ores were discovered early in the XVIIth century and the first blast-furnace was built at Saugus, Massachusetts, in 1644. Anthracite coal replaced charcoal in 1838 and coke production began in 1841.—E. J. B.

ECONOMICS AND STATISTICS

Iron and Steel Industries of the Far East. (Steel News, 1951, vol. 2, June, pp. 10–11). The economic conditions are surveyed. Manchuria is the main potential heavy industry complex in the Far East, apart from Japan.—T. E. D.

The 1950 Balance Sheet of Volta Redonda. O. H. Leonardos. (Mineração e Metalurgia, 1951, vol. 15, Mar.–Apr., pp. 268–270). [In Portuguese]. This is a brief note on the financial position of the Volta Redonda plant. Some figures of production for rolled products, coke, pig iron, steel, and coke by-products are given.—R. S.

Aspects of the Spanish Iron and Steel Industry. R. Guevara Lizaur. (Instituto del Hierro y del Acero, 1950, vol. 4, Jan.–Mar., pp. 24–38). [In Spanish]. Some objections to a forward impulse of the Spanish iron and steel industry are: Cost of plant; many raw materials must be imported; and necessity of a well-equipped rolling and forging industry. The production and consumption of iron ore and coal are surveyed. Reasons for the high fuel consumption per ton of rolled product and methods of reducing the consumption of coking coal are stated. The scrap position is reviewed in relation to the structure of Spain's industry in which production is 25% by Bessemer converters and 75% by open-hearth furnaces.—R. S.

What Must be the Foundations of the Argentine Iron and Steel Industry? E. Masle. (Tecnica e Industria, 1950, vol. 28, Dec., pp. 1352–1356). [In Spanish]. Argentine iron and steel requirements are measured against the number of steel-making furnaces and the ores, fuels, and transport available in the Republic. German and American methods using oxygen, high top pressure, and the electric low-shaft furnace are reviewed. The low-grade ore and lack of good coking coal are major reasons for considering the use of the low-shaft furnace for the production of pig iron and ferro-alloys in the Argentine.—R. S.

BOOK NOTICES

CHALMERS, B. "*The Structure and Mechanical Properties of Metals.*" 8vo, pp. ix + 132. Illustrated. London, 1951: Chapman and Hall, Ltd. (Price 18*s.*)

This is a book for the reader who has a general elementary background in physics and chemistry. The subject is surveyed in six chapters with the titles: The Structure of Pure Metals; The Structure of Alloys; The Effect of Distortion on Structure; The Effect of Heat Treatment on Structure; The Determination of Structure; and The Mechanical Properties and their Dependence on Structure.

On the whole, the book fulfils its purpose very well. There are only 123 pages of text, but an admirable balance is preserved, and the exposition is as logical and accurate (despite the author's reservation in the preface) as the terms of reference permit. In such a work drastic sacrifices must, of course, be made; Professor Chalmers has therefore reduced all account of technique to a minimum (the chapter on determination of structure merely lists the possible methods of examining metals, without any detail). Some will regret the complete absence of references, but the omission of distracting footnotes is, I think, justified. However, where recent work is quoted, such as the Frank theory of the origin of slip bands or Orowan's explanation of notch brittleness, of which there is no adequate account in existing textbooks, a reference should be given for the convenience of teachers.

The text is clearly illustrated by numerous graphs and diagrams (with one exception; in Fig. 79 the secondary creep rate under constant stress appears to increase gradually, without any steady period). A few more microphotographs might have been introduced with advantage, especially some of slip bands and twins in the chapter on the effect of distortion on structure. I feel also that more attention should have been drawn to logarithmic scales when these are used, as the student for whom the monograph is intended will probably not be thoroughly familiar with the device.

The survey is remarkably up-to-date; witness, for example, the section on the Young's modulus of aluminium alloys, and the lucid account in the same chapter of the theory of fracture—the latter might be read with profit by anyone concerned with the subject. Indeed, the whole book is a useful review of the present achievements and limitations of theory, as well as a good introduction to the study of metals.—K. E. PUTTICK

CLARK, F. H. "*Metals at High Temperatures.*" 8vo, pp. 372. Illustrated. New York, 1950: Reinhold Publishing Corporation. (Price $7)

This book claims to be the first on the 'new high temperature metallurgy.' In fact, it has appeared very shortly after a similar work by G. V. Smith, but differs from the latter in containing a vast amount of tabulated information on the mechanical properties of ferrous alloys at elevated temperatures. It is this catalogue of data, most of it previously published but hitherto widely dispersed and often difficult of access to British readers, that makes this book unrivalled as a work of reference.

The first two chapters are of an introductory nature and deal with the theoretical aspects of plastic flow and with testing equipment and procedures suitable for investigations in this field. In Chapter I plastic-flow phenomena are discussed from both the macroscopic and the microscopic points of view. An outline is given of the theory of plasticity, Prager's approach being adopted. This is followed by an analysis of creep behaviour and a brief consideration of time effects in plasticity, and of loading and unloading cycles; the inclusion of a hitherto unpublished treatment of the effect of strain rate in tensile testing is noteworthy. The author concludes from this discussion that the assumptions of plasticity theory render it invalid as a tool for dealing with measurements on real metals. This, although strictly correct, is perhaps over-emphasized in a book addressed to engineers and metallurgists, and leaves the reader with an unduly pessimistic picture of the state of plasticity theory at a time when advances of great practical importance are being made.

In the chapter on testing procedure the author very properly emphasizes the importance of long-time creep tests, preferably extending up to 10% of the expected life. Data derived from accelerated tests by extrapolation are treated with reserve throughout the book and are only given where better information is lacking. Likewise, the need is stressed for really accurate control of the variables

in creep testing. It is to be regretted that the description of testing apparatus and the consideration of the significance of the various tests is not more detailed.

In the main part of the book successive chapters deal with the high-temperature properties of plain carbon and low-alloy steels, chromium irons and moderately alloyed steels, highly alloyed austenitic steels, cobalt-base alloys, and nickel-base alloys. A further chapter contains some interesting details of alloys not commercially available which were developed in U.S. laboratories during war-time research. Wherever possible, details of the method of manufacture, heat-treatment, and specimen condition are given—a practice which is particularly commendable.

The book contains a brief survey of certain low-melting-point alloys, notably those having a lead, magnesium, or aluminium base, and concludes with chapters on manufacturing processes and scaling. In the last, the value of accelerated tests, in this case of corrosion resistance, is again questioned.

Although this book is almost above criticism as regards the selection of the information and the manner of presentation, there are certain limitations of scope which must be indicated and which will somewhat restrict its usefulness. Most serious of these is the omission of any reference to the yield properties of metals at high rates of deformation, and really high temperatures such as exist in hot-working processes. Nor are the properties of metals in the liquid state given. The book is concerned solely with those properties affecting the design of structures; it is all the more surprising, therefore, that no real attempt has been made to apply these data to behaviour under conditions of complex stress. Also omitted is any reference to measurements of internal friction and mechanical hysteresis at elevated temperatures. The majority of the results quoted are the products of American laboratories, and some comparison with British and German work would have been desirable. It is also a pity that the simultaneous use of the Centigrade and Fahrenheit temperature scales in the text has not been extended to the graphs.

These criticisms detract little from the value of a book which should be consulted by all beginning a research in this field and who wish to know what has already been done. An excellent bibliography of some 300 references is collected at the ends of the various chapters.—J. G. WALFORD

T. C. DUMOND. "*Engineering Materials Manual.*" 8vo, pp. 386. New York, 1951: Reinhold Publishing Corporation. (Price 36*s*.)

The 28 sections of which this volume is composed have all appeared in recent years in the journal 'Materials and Methods' and those dealing with ferrous materials such as 'Standard Engineering Steels,' 'High Strength Low-Alloy Steels,' and 'Cemented Carbides,' as well as those treating of 'Hard-Facing Materials,' 'Electroplated Coatings,' and similar matters, have been abstracted in the 'Journal of The Iron and Steel Institute.' Nevertheless, for the works metallurgist and the production engineer, this is a useful compendium.—J. P. S.

HOT DIP GALVANIZERS ASSOCIATION. "*International Conference on Hot Dip Galvanizing.* 8vo, pp. 161. Oxford, 1951: Zinc Development Association. (Price 30*s*.)

This book, which reports the proceedings of the International Conference on Hot Dip Galvanizing held at Copengahen in July 1950, is divided into six sections: Fundamental Aspects of Hot Dip Galvanizing, The Heating of Galvanizing Baths and Equipment, The Relative Merits of Flux Galvanizing and Dry Galvanizing, Galvanizing Residuals and Their Treatment, The Corrosion Resistance of Galvanized Coatings, and The Future of General Galvanizing. Abstracts of the more important papers will appear in the appropriate sections of the 'Journal of The Iron and Steel Institute.'—J. P. S.

JUNGBLUTH, HANS. "*Giessereitechnik.* I: *Eisengiesserei.*" 16mo, pp. 126. Berlin, 1951; Walter de Gruyter and Co. (Price DM 2.40)

This small book contains a comprehensive and practical treatment of the manufacture of iron castings. Owing to the requirements of space it is written in a form more dogmatic than analytical, but there is no doubt that it will make a useful primer for the serious student of the foundry art, as well as a handbook for the practical man.—J. P. S.

MOHLER, J. B. and H. J. SEDUSKY. "*Electroplating.*" 8vo, pp. 257. Illustrated. New York, 1951: Chemical Publishing Co., Inc. (Price $5)

This book has been written in a very readable manner, but it is disappointing to find that, in dealing with a rapidly developing field, there is comparatively little material which has not already appeared in books published nearly ten years earlier. With one exception, the references are not more recent than 1946. The book is divided into 25 chapters, of which only two contain more than 20 pages. Ten of the remaining chapters have between eight and ten pages, and 13 are four to seven pages in length.

There is an elementary treatment of the mechanism of electrodeposition in the first chapter. A table of standard electrode potentials in this chapter follows the European sign convention, but a table of cathode potentials in the appendix appears to be based upon the American convention.

The second chapter consists of a discussion of the laws and characteristics of plating baths. It contains a brief section, illustrated by diagrams, on methods of obtaining uniform distribution of the cathode deposit. A figure showing the relationship between cathode potential and current density is seriously misleading, because the captions for the ordinates and the abscissæ need to be interchanged. At the end of the chapter there is a section entitled 'Plating Range' in which only a reference is given for the Hull-cell test, and there is no description of it.

The third chapter, which deals with the control of a plating bath, gives only an outline of the possible methods that can be used. Physical properties of electrodeposits are described in the fourth chapter.

Preparatory steps in plating form the subject of the fifth chapter. Cleaning, degreasing, etching, etc., are dealt with only in a general manner, and for typical solutions and operating conditions one must turn to the appendix. The method of securing good adhesion of electrodeposits to steel by anodic polarization in sulphuric acid is not described.

The succeeding chapters, up to and including the seventeenth, are devoted to the deposition of various metals. The solutions recommended are, with the exception of that for lead plating, similar in composition to those in "Modern Electroplating" (The Electrochemical Society, N.Y., 1942). In the chapter on chromium plating, numerals have been omitted from the graphs of hardness and current density *versus* bath temperature. No explanation is suggested for the action of the sulphate radical in promoting the electrodeposition of chromium from a chromic acid solution. Remedies for troubles which are likely to be encountered in operating the various baths are comprehensively dealt with in the twentyfourth chapter. Analytical procedures for all the baths can be derived from the twentyfifth chapter.

Electroplated alloys are discussed in the eighteenth chapter. In an introductory section on the conditions which must be fulfilled before alloy plating can occur, it is stated that, with simple ions, a ten times change in the ionic concentration alters the deposition potential by 0·06 V. This applies, however, only to singly charged ions, and simple ions of most of the common metals are doubly charged. Bath formulæ and operating conditions are given for the following alloys: Brass, bronze, lead–tin, lead–tin–copper, nickel–cobalt, and tin–zinc.

Copper plating, to protect selected areas of steel during carburization, receives detailed attention in the next chapter. A literature reference is given for a simple chemical test to determine the porosity of the coating, but the test is not described.

This chapter is followed by a very short one on alloys produced by thermal diffusion of dual coatings. There are figures illustrating the relationship between diffusion alloys, and three types of binary phase diagram.

The twentyfirst chapter affords guidance in selecting a plating bath to fulfil particular requirements. Some qualitative adhesion tests are mentioned, but quantitative methods are ignored.

In a new American book on electroplating one might reasonably have expected the next chapter, which is entitled 'Continuous Plating,' to include an authoritative account of the various electrotinning processes that are now being

operated in the U.S.A. Instead there is a short description of the 'Ferrostan' process only. A more detailed treatment is stated to be outside the scope of the book, yet in their introduction, the authors claim that it is written for the trained metallurgist, engineer, and chemist. The first two of these are unlikely to be satisfied by this account.

The twenty-third chapter is concerned with the applications of electroplating, and consists mainly of a table of articles and the types of electrodeposit which are commonly applied to them.

At the end of the book there is a six-page glossary. There are numerous small errors throughout the book which suggest lack of care in proof-reading.—F. W. SALT

THE PHYSICAL SOCIETY. "*Reports on Progress in Physics.*" Vol. XIV (1951). 8vo, pp. iv + 412. London, 1951: The Society. (Price 50*s.*)

This volume contains papers on 'Recent Advances in Ultra-Violet Absorbtion Spectroscopy,' 'The Diffraction Theory of Aberrations,' 'The Miscophysics of Clouds,' 'A Critical Study of Ionosphere Temperatures,' among other things; and no less their four papers on aspects of nuclear physics. There is little of direct interest to the metallurgist, but it is always a pleasure to look at the volumes in this series, which keeps up its high standards of form and content.—J. P. S.

"*Progress in Metal Physics*, 2." Editor: Bruce Chalmers. 8vo, pp. viii + 213. London, 1950: Butterworth's Scientific Publications. (Price 45*s.*)

The advent of the dislocation theory of metals 17 years ago can be regarded as having a significance in the development of the physics of metals comparable to the discovery of the periodic system of the elements in the development of chemistry. Up to 1935 a wealth of painstakingly acquired knowledge about pure metals and alloys had accumulated and was waiting to be built into a coherent pattern by the unifying principles of theory. Since then ever greater strides have been made in every branch of metal physics; in fact theoretical advances occasionally follow—and even overtake—one another with such rapidity as to tempt one to wish at times for a brief respite in which to digest the wealth of new material.

The difficulty of keeping pace with new work is perhaps most acutely felt by the industrial research worker who, occupied by a specific and often urgent investigation has little opportunity to delve in the diverse journals devoted to metal physics, to extract implications relevant to his work from branches of the science not necessarily very close to his own, and to form a balanced picture of the changing scene. Here the annual "Progress in Metal Physics" series comes to his rescue; it does just this work for him. Those acquainted with the excellent first volume will hardly need a further recommendation of the present, second volume, apart from the remark that it is by all standards on a par with its predecessor. The book contains seven well-referenced chapters on subjects in which considerable progress has been made in recent years.

In the first and longest chapter H. Lipson presents a most instructive survey of the field of order–disorder changes in alloys, and arrives at the conclusion that the theory is reasonably complete in general outline and could be said to be almost perfectly satisfactory. This is reassuring.

Molecular—or perhaps one should say ionic—rate processes in physical metallurgy are discussed by I. I. Betcherman. This subject merits greater attention on the part of metal physicists than it has hitherto received. Its introduction here should be welcome, and bears witness to the critical eye of the editor in the selection of topics. In problems of creep, rapid steady flow at high temperatures, intermetallic diffusion, recovery, and recrystallization, rate theory can provide a basis for the description which should prove to be more rational than the empirical power-laws still frequently employed in creep and flow problems. In contrast with this, the work of Frederickson and Eyring, reviewed by Betcherman, in which the stress/strain curve of a metal is analysed in terms of systems of Hookian springs and of dashpots having a stress/strain-rate relationship derived from rate theory, is overschematized and is not likely to find ready acceptance by the metallurgist who knows how metals actually do behave. Although rate theory should prove most valuable as an additional weapon in the armoury of the physical metallurgist, it must not, however, be allowed to overshadow detailed, concrete observations of structural changes. A survey of the scope and limitations of rate theory would have added value to this well-presented chapter.

A well-documented paper by W. Boas and J. K. Mackenzie deals with the anisotropy of the electrical conductivity, elastic constants, coefficients of diffusion, and thermal expansion of metal crystals. Very little of a hypothetical nature is to be found in this chapter, and it should provide a good introduction to a subject the potential importance of which is liable to be underestimated by workers habitually dealing with polycrystalline aggregates.

In contrast with the preceding sections, H. G. Warrington's essay on developments in magnesium alloys is more technological and should perhaps be particularly recommended to the 'pure' metal physicist for whom the 'feel' of technological methods may have a decisive influence in the formulation of his own researches. The statement on page 122 that alloys formed from elements of high purity possess an inherently finer grain size than alloys of commercial purity is most interesting and will probably stimulate thought concerning current views on grain refining.

The last three chapters consist of a symposium on polygonization. R. W. Cahn introduces the reader to the subject in a paper dealing with the relation of polygonziation to internal strains and its rôle in recrystallization. A. Guinier and J. Tennevin describe researches on polygonization in which they have applied their X-ray technique of focusing and thus resolved the structure of individual Laue spots.

C. Crussard and co-workers contribute a final chapter on polygonization in strongly deformed metals. The three chapters of this symposium summarize in essence the present-day knowledge of polygonization. From the point of view of the metal physicist the work is most elegant and satisfying. As to the guidance the metallurgist and metal technologist can derive from it at its present stage, there appears to be room for debate. It may well be that the third volume of this series will provide an answer to this question.

The chief merit of the book is perhaps that it allows the research worker, the metallurgist, and the student to orientate themselves. It shows where we stand today, and it is the knowledge of this position in a rapidly developing science which can serve as the most rational guide as to where and how to proceed tomorrow.—P. FELTHAM

ROGERS, B. A. "*The Nature of Metals.*" 8vo, pp. vi + 247. Illustrated. Cleveland, Ohio, 1951: American Society for Metals; Ames, Iowa: Iowa State College Press. (Price $3)

This book is intended to give its readers some idea of the nature and behaviour of metals, but it is addressed not only to metallurgists but more to persons who wish to know about metals either because of immediate need or because of a desire to expand their scientific and technical knowledge.

In the first chapter the reader is introduced to the periodic table, and to the appearance of metals under the microscope. The principle of illumination of an opaque section is clearly illustrated and the principles of etching adequately described.

Chapter 2, 'How Atoms Are Arranged in Metals,' is illustrated with photographs of spheres and with diagrams which adequately illustrate the space lattices of crystals of the different metals. The chapter concludes with a few paragraphs describing how crystallographic planes are specified. Alloys in general are described in chapter 3 in which the author introduces the reader to alloys consisting of two completely immiscible metals, *i.e.* iron and lead, to metals that have complete mutual solubility such as silver and gold, and to a simple constitutional diagram.

In the next chapter (the fourth) somewhat more complicated constitutional diagrams are described, *i.e.*, constitutional diagrams of tin–lead alloys, magnesium–lead alloys, and copper–zinc alloys. Brief reference is also made to intermetallic compounds.

Solidification is adequately covered by chapter 5 in which the author describes the production of single crystals, and the freezing of a metal in an ingot mould. Chapters 6 and 7 are devoted to an elementary study of the movement of

atoms in solid metals and to the effects of atomic movements. Considerable attention is paid to precipitation hardening. Chapters 8 and 9 are devoted to iron and steel. The changes that take place on cooling through the transformation range are clearly described, and the reader is introduced to the elements of hardening.

Chapter 10 describes how metals are deformed and chapter 11 is devoted to a study of recrystallization. Oxidation and corrosion form the subject matter for chapter 12, and the volume concludes with an appendix and a list of questions.—J. FERDINAND KAYSER

SULLIVAN, J. W. W. "*The Story of Metals.*" 8vo, pp. x + 290. Illustrated. Cleveland, 1951 : American Society for Metals ; Ames, Iowa, The Iowa State College Press. (Price $3)

This is a popular but interesting book and traces the story of metals from the earliest ages to this, the atomic age. It records the Jewish legend according to which when the Temple at Jerusalem was completed, King Solomon gave a feast to the artificers employed in its construction, and on unveiling the throne found that a blacksmith had usurped the seat of honour on the right of the king's place, and, coming to the atomic age, tells of Americium, Astatine, Francium, and other metals recently isolated and identified during atomic-bomb research.

The first chapter is devoted to the origin of metals and briefly describes the formation of mineral and metal deposits during past ages, and the isolation of hitherto unknown metals during atomic-bomb research. Chapters 2 and 3 deal with man's early use of metals and his first endeavours to produce and work them. A good word is put in for the alchemist of the Middle Ages whose work stimulated interest in chemistry, medicine, and metallurgy, and thereby indirectly aided the foundation of the modern chemical industries. Chapter 4 covers metallurgical developments made during the period A.D. 1500 to 1800. Just as the two past world wars stimulated research and development, so did the introduction of gunpowder during the XIVth century. Its growing potency called for more metals for cannons and projectiles and for better metals for both purposes.

The author tells us that one of the best-kept secrets of all time was that of the production of tinplate, which was kept secret for nearly 400 years. From the middle of the XIIIth century, sheets of hammered iron were coated with molten tin by a process developed in the Harz mountains of Germany, and the secret was not disclosed until 1612, a tinplate industry being finally established in Wales about 1720.

Chapter 5, "The March of Science," calls attention to scientists of the distant past and the near past to whom the present day owes so much ; to the ancient 'magus' who preached fear of a god and sacrifice to buy off the diety's wrath ; to Archimedes, Nicolaus Copernicus, Galileo, and many others right down to Marie Curie, who may be said to have been the first worker in the atomic field.

Chapters 6, 7, 8, and 9 take one through the modern development of iron and steel and non-ferrous metals in general, whilst chapter 10 is devoted to the future of metals. Finally, the book concludes with a glossary of technical terms.

Although a popular book, this is not one to treat lightly; it is well worth reading.—J. FERDINAND KAYSER

NEW PUBLICATIONS

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Proceedings.*" Vol. 50, 1950. "*Committee Reports, Technical Papers.*" 8vo, pp. xii + 1490. Illustrated. Philadelphia, 1951 : The Society. (Price $12)

AMERICAN SOCIETY FOR TESTING MATERIALS. "1950 *Supplement to Book of ASTM Standards Including Tentatives.*" Part 3. "*Cement, Concrete, Ceramics, Thermal Insulation, Road Materials, Waterproofing, Soils.*" 8vo, pp. xiii + 350. Philadelphia: The Society. (Price, Parts 1–6, $16.80)

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1949." Part II. "*Overseas Countries.*" 4to, pp. iv + 395. London : The Federation. (Price 15*s.*)

BRITISH IRON AND STEEL RESEARCH ASSOCIATION. "*Catalogue of Irons and Steels for Research Purposes.*" Prepared by the Metallurgy (General) Divisional Laboratory. 4to, pp. ix + 96. London, 1950: The Association.

BRITISH STANDARDS INSTITUTION. B.S. 778 : 1951. "*Steel Pipes and Flanged Joints for Hydraulic Purposes.* 8vo, pp. 36. London : The Institution. (Price 4*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 812 : 1951. "*British Standard Methods for the Sampling and Testing of Mineral Aggregates. Sands and Filters.*" 8vo, pp. 57. London: The Institution. (Price 6*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1713 : 1951. "*Cast Iron Smooth Tube Economisers with Pressed Socket Joints.*" 8vo, pp. 13. London: The Institution. (Price 2*s.*)

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ERDMANN-JESNITZER, F. "*Werkstoff und Schweissung I.*" 8vo, pp. xxiv + 1002. Illustrated. Berlin, 1951 : Akademie-Verlag. (Price DM 160.– for 2 vols.)

"*Fourth Empire Mining and Metallurgical Congress held in Great Britain, July 9th–23rd* 1949." Proceedings. 8vo, Part I. Pp. xx + 551. Part 2. Pp. xx + 555–1139. London, 1950. (Price 40*s.*)

GEOLOGICAL SURVEY OF GT. BRITAIN. "*The Northampton Sand Ironstone. Stratigraphy, Structure and Reserves.*" By S. E. Hollingworth and J. H. Taylor. 8vo, pp. viii + 211. Illustrated. London, 1951: H.M. Stationery Office. (Price 17*s.* 6*d.*)

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HEILIGENSTAEDT, W. "*Wärmetechnische Rechnungen für Industrieöfen.*" (Stahleisen-Bücher Bd. 2.) 3. Auflage. 8vo, pp. xv + 488. Illustrated. Düsseldorf, 1951: Verlag Stahleisen m.b.H. (Price DM 44.–)

INSTITUTE OF PHYSICS. "*Some Aspects of Fluid Flow.*" Being the Papers presented at a Conference organized by The Institute of Physics at Leamington Spa on 25th–28th October 1950 and the Reports of the Conference Discussion Groups. 8vo, pp. viii + 292. Illustrated. London, 1951 : Edward Arnold and Co. (Price 50*s.*)

KOCKUMS JERNVERKS, A.B. "*Kockumverken vid Ronneby*å*n.*" En hundraårig industriell utveckling av Artur Attman. La 8vo, pp. 384. Illustrated. Kallinge, 1951.

MANTELL, C. L. "*Adsorption.*" Pp. viii + 634. New York, 1951 : McGraw-Hill Book Co., Inc., London: McGraw-Hill Publishing Co., Ltd. (Price $9)

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"*Metal Statistics* 1950." Forty-Third Annual Edition. Sm. 8vo, pp. 794. New York : American Metal Market. (Price $2)

MONYPENNY, J. H. G. "*Stainless Iron and Steel.*" With a Foreword by F. C. Thompson. Volume One. "*Stainless Steels in Industry.*" Third edition revised. 8vo, pp. xii + 524. Illustrated. London, 1951 : Chapman and Hall, Ltd. (Price 45*s.*)

NORTH, S. H. "*Compressed Air in Mining and Industry.*" 8vo, pp. ix + 170. Illustrated. London, 1951 : Sir Isaac Pitman and Sons, Ltd. (Price 18*s.*)

RICCI, J. E. "*Phase Rule and Heterogeneous Equilibrium.*" 8vo, pp. 505. Illustrated. New York and London, 1951 : D. Van Nostrand Co. (Price $12)

SALMON, W. H. AND E. N. SIMONS. "*Foundry Practice.*" 8vo, pp. xiii + 384. London, 1951 : Sir Isaac Pitman and Sons, Ltd. (Price 30*s.*)

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IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Effect of Hydrogen on the Properties of Low-Alloy Steels

By J. D. Hobson, B.Sc., A.R.I.C., A.I.M., and C. Sykes, D.Sc., F.R.S.

SYNOPSIS

A method is described by which hydrogen is introduced into steel specimens by heating them in the gas at high pressures. The deleterious effect of hydrogen on the ductility of a number of low-alloy steels has been investigated and shown to be reproducible, provided that their heat-treatment is also considered. Hydrogen additions have the same effect whether carried out by electrolysis or by the high-pressure technique.

Introduction

It is now established that the ductility of steel as measured by the tensile test is reduced if significant amounts of hydrogen are present in the steel, and it is generally agreed that this brittleness may be an important factor in the formation of hair-line cracks, snow-flakes, fish-eyes, etc.

Hitherto, no systematic work has been carried out to determine whether the effect of hydrogen varies from cast to cast of a given steel, and although it is considered that the embrittling effect is more marked at higher tensile strengths, this has not been demonstrated in a systematic manner.

The work described in this paper deals with these two problems and provides evidence of the susceptibility to embrittlement of certain steels used for the production of large forgings.

In previous experimental work four methods have been employed to obtain varying hydrogen contents:

The use of naturally occurring hydrogen.[1, 2, 3] It is difficult to obtain specimens which naturally contain known amounts of hydrogen, particularly in excess of 2 ml./100 g.

Treatment in hydrogen at atmospheric pressure at temperatures above the α/γ change point.[4, 5, 6] This method enables an adequate amount of hydrogen to be introduced, but is not practicable for retaining the hydrogen if the specimens have to be tempered to any given tensile strength.

Electrolysis.[4, 6] This method enables hydrogen to be introduced into fully heat-treated test pieces, but it is very erratic.

Treatment at temperatures up to 600° C. in hydrogen at elevated pressures.[7] The amount of hydrogen introduced is controlled by varying the pressure and temperature, and can be achieved without significantly modifying the structure and mechanical properties of the specimen.

This last method has been used for the major portion of the work described in this paper.

Preliminary Investigations

Early investigations at the Brown-Firth Research Laboratories, confirmed that the ductility of steel, as measured by elongation and reduction in area in the ordinary tensile test, was adversely affected by the presence of hydrogen, and it was shown that for each steel investigated it was possible to draw a smooth graph relating hydrogen content with percentage reduction in area.

In these early experiments, the hydrogen was added either by heating the sample in hydrogen or by cathodic electrolysis. The points obtained by either method fell on the same curve, and it was shown that if hydrogen was removed by ageing or by vacuum extraction, the original ductility could be recovered. Typical results of an experiment of this type, on 3% Cr–Mo steel *A*, are given in Table I.

The electrolytic impregnation method was found to be unsatisfactory, as it was difficult to add a desired quantity of hydrogen except by a long process of trial and error. It was, therefore, decided to construct an apparatus in which samples could be heated at chosen temperatures in a hydrogen atmosphere of known pressure.

HYDROGEN ADDITION AND DETERMINATION

DESCRIPTION OF HYDROGENATION APPARATUS

A diagram of the apparatus is shown in Fig. 1. The sample tube is approximately 1 in. internal dia. and will easily accommodate a standard tensile test

Manuscript received 21st September, 1950.

Dr. Sykes is at the Brown-Firth Research Laboratories. Mr. Hobson, who was until recently at the Brown-Firth Research Laboratories, has now joined the staff of Hadfields, Ltd.

Table I

RESULTS OF EXPERIMENTS ON HYDROGENATION OF 3% Cr-Mo STEEL *A*

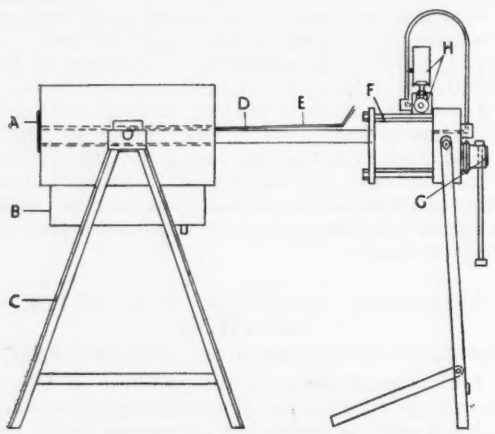
Treatment	Hydrogen, ml./100 g.	Tensile Properties			
		Yield Point, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	Reduction in Area, %
Heated in vacuum 2½ hr. at 600° C.	Nil	34·0	42·6	30·0	73·3
As received	0·2	53·3	63·0	22·0	70·0
Heated in air, 4 hr. at 700° C.	0·4	37·1	47·0	28·5	75·5
Heated in H_2, 4 hr. at 700° C.	1·3	39·2	48·5	24·5	59·0
Electrolyzed in 2% H_2SO_4, 24 hr. at 95° C., 9 amp.	0·8	49·2	58·9	22·0	68·0
Electrolyzed in 10% NaOH, 24 hr. at 100° C., 5 amp.	2·5	57·8	64·2	18·5	49·5
Electrolyzed in 2% H_2SO_4, 8 hr. at R.T., 5 amp.	2·9	53·5	61·5	17·5	51·0
Electrolyzed in 10% NaOH, 24 hr. at R.T., 5 amp.	2·9	57·8	64·0	18·0	48·0
Electrolyzed in 2% H_2SO_4, 48 hr. at R.T., 5 amp.	4·9	51·4	60·6	16·0	39·0
Electrolyzed in 2% H_2SO_4, 24 hr. at R.T., 5 amp.	6·7	51·7	60·3	15·0	35·5

piece with ¾-in. Whitworth heads and a 1·8 in. × 0·505 in. dia. section. The tube is of 18% chromium–8% nickel–titanium-stabilized steel, with a wall thickness of $\frac{5}{32}$ in. This quality has adequate creep resistance at 600° C. and at the stresses present. An austenitic steel is essential for this portion of the apparatus to minimize hydrogen losses by diffusion through the heated tube walls. All the parts of the pressure vessel and its thrust bolts are made from rustless steel to avoid internal corrosion. The pressure vessel, 4 in. internal dia. and 6 in. long, is fitted with a large removable port in the lower segment at the opposite end to the sample tube. Hydrogen is supplied from cylinders at 120 atm. to the apparatus, which is designed to withstand 70 atm. at 600° C. with a large factor of safety. The hydrogen is admitted through a high-pressure valve, and a partial vacuum may also be produced through a second valve. The pressure is registered on a large gauge permanently connected to the top of the pressure vessel.

The temperature of the central 11-in. zone of the furnace is maintained to within ± 2° C. by a potentiometric indicator control operated by a thermocouple, which is fixed to the centre of the heated zone of the sample tube. The end zones, each 3 in. long, are regulated by a second similar two-point controller, which is necessary because the heat losses along the tube vary considerably with hydrogen pressure. The end zones are held to within ± 10° C. of the temperature of the central zone.

Operation of the Apparatus

The furnace is heated to the selected temperature and the water vessel is supported so that it is above the tube, with the latter inclined at an angle of about 30° to the horizontal. The specimen is then inserted through the water vessel port and pushed down the tube until it is centrally placed in the heated zone where it is arrested by a stop. About 600 ml. of water are poured into the water vessel and the port



A. Furnace—3-zone
B. Resistances
C. Furnace stand
D. Sample tube
E. Thermocouples
F. Water bath
G. Sample port
H. Valves and gauge

Fig. 1—Diagram of apparatus for the high-pressure hydrogenation of steel specimens

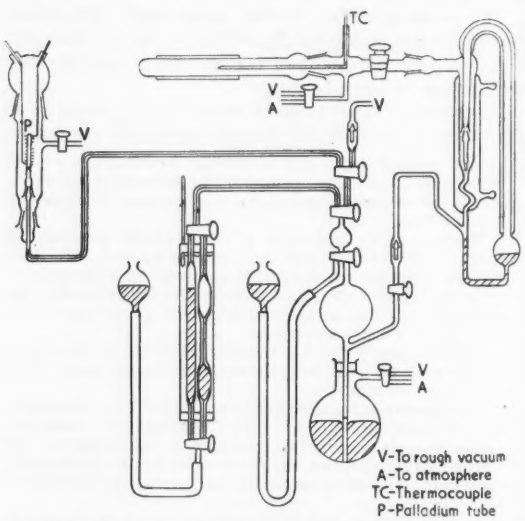


Fig. 2—Diagram of apparatus for the determination of hydrogen content of fractured tensile test pieces

is screwed in ; finally the apparatus is lowered to bring the specimen tube horizontal. Air is expelled by a mechanical pump and a small quantity of hydrogen admitted from the cylinder. This hydrogen is burnt at the evacuation port, so eliminating any remaining air. More hydrogen is then added to give the desired pressure and the specimen is heated until equilibrium is reached.

When hydrogen impregnation is considered complete, the sample tube is rapidly removed from the furnace and raised, so causing the specimen to slide down and be quenched in the water bath while still under hydrogen pressure. The tube is at once replaced in the furnace and the hydrogen is released and ignited. The port is unscrewed and the specimen is removed, cooled to room temperature, and subjected at once to the prearranged mechanical test. The hydrogen content of the fractured specimen is then determined by heating the pieces in a vacuum furnace at 650° C.

About five minutes elapse between the quenching of the specimen and the commencement of the hydrogen determination. It is important to keep this time interval as short as possible to minimize any effects due to segregation of the hydrogen into minute pores, and losses of hydrogen by diffusion from the metal surface.

It is also important to use the whole test piece for the hydrogen determination.

METHOD OF DETERMINATION

The hydrogen contents of the test pieces were determined by heating part or all of the specimens in an evacuated furnace at 650° C.

The earlier results were obtained on cylindrical specimens $\frac{1}{2}$ in. × $\frac{1}{2}$ in. dia., turned from the test piece immediately after fracture. The two vacuum furnaces are modified forms of the apparatus devised by Newell[8] and described later by Wells and Barraclough.[9] Samples are introduced and removed by means of a mercury lift and transferred to an electrically heated furnace on a floating platform. The evolved gases are rapidly removed by a two-stage mercury-vapour pump and collected in a Töpler pump connected to calibrated bulbs. The original apparatus is now fitted with a palladium diffusion unit to determine the hydrogen content of the gas.

Later, the whole specimen was analysed and a vacuum furnace and pumping system were built for this purpose (*see* Fig. 2). The furnace tube, 9 in. long × 1 in. dia., accommodates the whole of the fractured test piece. This minimizes segregation effects and gives sufficient gas for the analysis obtained by palladium diffusion to be checked by normal methods. The apparatus is designed so that the vacuum can be broken and partially restored in the furnace section while the pumping system is operating ; thus rapid operation on freshly broken specimens is possible.

THEORETICAL CONSIDERATIONS

Sievert's law states that the solubility of gases in metals is proportional to the square root of the applied gas pressure. Thus if 64 atm. are applied, the quantity of gas introduced will be eight times that dissolved at atmospheric pressure.

At 600° C. the solubility of hydrogen in ferritic steels is of the order of 1·1 to 1·3 ml./100 g. ; using

Table II

ANALYSES OF STEELS USED IN INVESTIGATIONS INTO HYDROGEN EMBRITTLEMENT

Steel	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %	Sn, %
3% Chromium–Molybdenum Steels									
A	0·26	0·21	0·50	0·014	0·021	0·26	2·94	0·51	...
B	0·26	0·26	0·53	0·006	0·015	0·21	3·32	0·40	0·014
C	0·30	0·28	0·58	0·011	0·010	0·23	3·12	0·46	0·021
D	0·29	0·34	0·52	0·009	0·013	0·24	3·11	0·42	0·015
E	0·26	0·26	0·41	0·025	0·018	0·39	3·15	0·45	0·053
F	0·32	0·21	0·49	0·012	0·020	0·21	3·49	0·46	0·018
G	0·27	0·23	0·49	0·009	0·014	0·27	3·15	0·41	0·015
H	0·30	0·27	0·69	0·021	0·022	0·12	3·29	0·63	...
I	0·28	0·22	0·64	0·027	0·025	0·17	3·23	0·57	...
J	0·28	0·25	0·56	0·033	0·022	0·20	3·26	0·41	...
3½% Nickel Steels									
K	0·32	0·19	0·70	0·012	0·014	3·46	0·69	...	...
L	0·30	0·18	0·60	0·010	0·015	3·69	0·12	...	...
0·4% Carbon Steels									
M	0·35	0·20	0·72	0·033	0·030	0·42	0·14	...	...
N	0·36	0·30	0·67	0·037	0·032	0·10	0·12	...	...
1% Nickel Steels									
O	0·37	0·22	0·79	0·009	0·011	1·18	0·08	...	...
P	0·36	0·19	0·76	0·028	0·023	1·18	Tr.	...	...
2¼% Nickel–Chromium–Molybdenum Steel									
Q	0·23	0·25	0·51	0·026	0·019	2·36	0·38	0·41	...

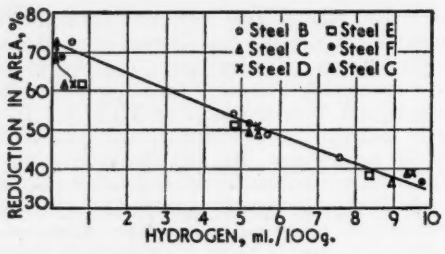


Fig. 3—Relationship between hydrogen content and percentage reduction in area for six different casts of 3% Cr–Mo steel

the apparatus at its maximum working pressure, specimens can be produced with hydrogen contents as great as 9–10 ml./100 g. The range 0–10 ml. covers the hydrogen content of liquid steel as made by normal processes.

It is possible to introduce the hydrogen without any noticeable effect upon the heat-treatment of the steel. If 600° C. is liable to cause tempering of hardened specimens, then the operating temperature can be lowered, and in the work to be described samples were usually hydrogenated at least 50° C., and preferably 100° C., below the tempering temperature.

At lower temperatures, it is permissible to raise the hydrogen pressures, and tests have been successfully carried out with hydrogen at 120 atm. and 360° C.; about 4 ml./100 g. were present after treatment, as the lowered solubility caused a fall in the total hydrogen introduced. This was an adequate value, as it caused severe embrittlement of the specimen (*see* p. 213).

HYDROGEN AND THE TENSILE TEST

Most of the experimental data have been obtained on steel qualities used in large forgings and are subdivided according to type in this paper. The analyses of steels used are given in Table II.

3–3½% Cr–Mo Steel

(i) *Reproducibility of Results*—To assess the reproducibility of the results obtained, three tensile test pieces were made from each of six different casts of 3% Cr–Mo steel (steels *B*, *C*, *D*, *E*, *F*, *G*) after oil-hardening pieces of 1¼-in. bar from 900° C. and tempering at 670° C.

One test piece from each batch was vacuum-heated before testing, another was heated in hydrogen at 225 lb./sq. in., and the third was hydrogenized at 900 lb./sq. in. They were all heated for 2 hr. at 600° C. The pressure-treated test pieces were quenched in the apparatus before releasing the pressure. The specimens were fractured at once and the hydrogen content was determined on the pieces by vacuum heating immediately afterwards.

The results of hydrogen determinations and tensile tests are given in Table III. The approximately linear

Table III

RESULTS OF TENSILE TEST AND HYDROGEN DETERMINATIONS ON SIX CASTS OF 3% Cr–Mo STEELS *B–G*

Steel	Hydrogen Treatment*	Hydrogen, ml./100 g.	Tensile Properties			
			Yield Point, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	Reduction in Area, %
B	Results from previous experiments	0·5	44·0	56·0	25·0	72·5
		4·8	45·5	55·0	20·5	54·5
		5·7	44·5	55·0	18·5	49·5
		7·6	46·3	55·3	16·0	43·5
C	*a*	<0·1	44·3	53·3	23·5	70·5
	b	5·4	46·3	53·3	17·5	49·0
	c	9·0	45·3	54·0	16·5	37·0
D	*a*	<0·1	45·0	55·0	24·5	70·5
	b	5·4	46·5	55·8	20·5	50·5
	c	9·5	46·5	56·8	16·5	39·0
E	*a*	0·1	42·5	54·5	23·5	70·5
	b	4·8	46·5	55·0	19·5	52·0
	c	8·4	47·3	55·8	17·5	39·0
F	*a*	0·2	47·0	57·8	23·5	68·0
	b	5·2	46·5	56·8	21·0	52·0
	c	9·7	48·2	57·6	16·5	37·5
G	*a*	0·1	43·0	52·3	25·5	72·5
	b	5·2	46·0	53·8	19·5	50·5
	c	9·4	46·5	54·0	16·5	39·0

* Treatment *a*—Heated in vacuum for 2 hr. at 600° C.
b—Heated in hydrogen for 2 hr. at 600° C. and 225 lb./sq. in.
c—Heated in hydrogen for 2 hr. at 600° C. and 900 lb./sq. in.

Table IV

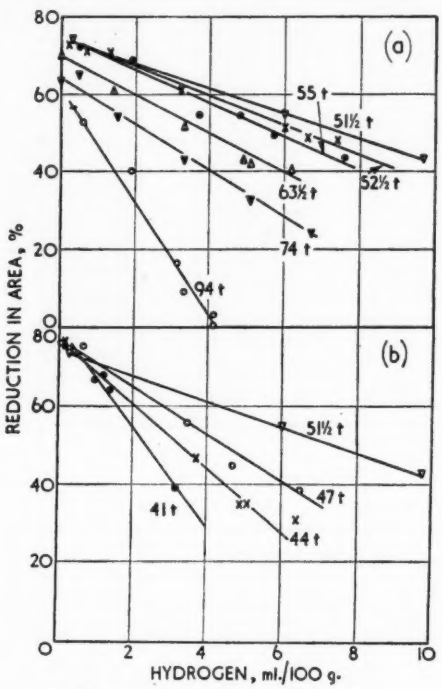
HEAT-TREATMENT AND MAXIMUM STRESS OF 3% Cr–Mo STEEL *B*

Nominal Maximum Stress, tons/sq. in.	Temperature at which Oil-Hardened, °C.	Tempering Time, hr.	Tempering Temp., °C.	Method of Hydrogenation
41	920	23	720	Electrolytic
44	900	4	720	Pressure
47	900	2	700	,,
51·5	900	1	670	,,
52·5	900	1	650	Electrolytic
55	900	1	650	Pressure
63·5	900	1	580	,,
74	900	1	560	,,
94	900	1	425	,,

relationship between percentage reduction in area and hydrogen content is shown in Fig. 3; the loss of ductility with increasing hydrogen content is quantitatively similar for steels of a common type.

(ii) *Effect of Maximum Stress on Susceptibility to Hydrogen Embrittlement*—A systematic examination was carried out on the combined effects of hydrogen and heat-treatment on 3% Cr–Mo steel *B*. Starting from 1½-in. dia. rolled bar, all specimens were turned to 1-in. dia. prior to heat-treatment. Various treatments were used to vary the maximum tensile strength of the various series of bars (*see* Table IV).

The relationship between maximum stress, reduction in area, and hydrogen content is shown in Figs. 4*a* and *b*. Examination of the test pieces shows that the steel is readily hydrogen-embrittled when



(*a*) 94 tons/sq. in. to 51½ tons/sq. in. max. stress
(*b*) 51½ tons/sq. in. to 41 tons/sq. in. max. stress

Fig. 4—Relationship between maximum stress, hydrogen content and percentage reduction in area for 3% Cr–Mo steel *B*. (Figures against curves show maximum stress, tons sq. in.)

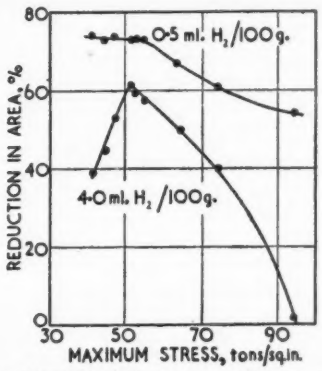


Fig. 5—Relationship between maximum stress and percentage reduction in area at two levels of hydrogen content for 3% Cr–Mo steel *B*

hardened and tempered to give a high maximum stress. As the latter is lowered by progressive tempering, the influence of hydrogen rapidly decreases until the maximum stress has fallen to 51½ tons/sq. in. If the steel is subjected to prolonged tempering above 670° C. in the absence of hydrogen, the maximum stress can be lowered still further without loss of ductility. When hydrogen is present, however, the embrittlement graph becomes steeper (Fig. 4*b*) as the maximum stress falls. Thus, there is a sharply defined optimum tempering temperature where hydrogen embrittlement is at a minimum. This point is clearly emphasized in Fig. 5; the pronounced maximum in the curve for 4 ml. hydrogen/100 g. corresponds to minimum susceptibility to embrittlement.

A photograph showing typical fractures from the series is reproduced in Fig. 6, and micrographs of the structures in Fig. 7. When the steel is subjected to hydrogenation after abnormally long tempering, as in the 41- and 44-ton series, the resultant fractures exhibit a dull surface with a nodular appearance. Such fractures appear to be associated with hydrogen, since in hydrogen-free tensiles the fractures are normal.

In the case of the 94-ton-maximum-stress samples, hydrogen causes the appearance of notch sensitivity. The 94-ton test piece shown in Fig. 6 was broken through the threads. A second test piece having the same ¾-in. Whitworth screwed head and a parallel portion of 0·423 in. dia., was fractured on the 'pop' marking the gauge length at 93·3 tons/sq. in. There was no obvious necking and the reduction in area was only 3·5%. These two test pieces contained about 4 ml. hydrogen/100 g.

Specimens having low values of maximum stress are considerably spheroidized. The minimum susceptibility to hydrogen embrittlement is in the region where tempering is nearly completed, but where spheroidization is not likely to be rapid. Partially tempered structures, being harder, are less ductile, and the presence of hydrogen causes increasing loss of ductility with rising maximum stress. This results in an almost completely brittle fracture at 94 tons maximum stress with a hydrogen content of 4 ml./100 g., whereas the heavily spheroidized structures are

quite ductile when no hydrogen is present, but are significantly embrittled when it is introduced.

These results show that the structure and heat-treatment of the samples, together with the tensile strength, are factors which have to be taken into account when investigating the effects of hydrogen on ductility.

(iii) *Comparison of Electrolytic and High-Pressure Hydrogenation*—Six tensile test pieces having a gauge length of 2 in. × 0·564 in. dia. were prepared from a 3% Cr–Mo steel *B* bar of $1\frac{1}{8}$ in. dia. after oil hardening from 900° C. and tempering at 650° C., giving a maximum stress of 52 tons/sq. in.

Hydrogen was introduced into four specimens by electrolysis in 2% sulphuric acid with varying current densities. Electrolysis at the head and shoulders of the specimen was prevented by coating with a thin layer of vacuum wax. A fifth specimen was saturated with hydrogen by heating for 2 hr. in a furnace with a hydrogen atmosphere and then rapidly quenching in water.

Each specimen was tested in a tensile machine and records kept (*see* Table V). The sixth tensile test piece was fractured without hydrogen treatment. Hydrogen was determined on $\frac{1}{2}$ in. × $\frac{1}{2}$ in. dia. cylinders.

About ten months later a further six tensile specimens were prepared from the same bar of 3% Cr–Mo steel *B*, but these were made with 1·8 in. gauge length and 0·505 in. dia. to suit the high-pressure apparatus described earlier. They were soaked in hydrogen at various pressures from one to 60 atm. at 600° C. for 2 hr., preliminary work having shown that saturation was reached in this period. They were then quenched inside the pressure apparatus, and subjected immediately to the tensile test (*see* Table VI). After fracture, the two broken pieces were vacuum-heated at 650° C. in the apparatus shown in Fig. 2.

Of the parameters measured in the tensile test the percentage reduction in area was chosen as the most sensitive to hydrogen embrittlement; it is plotted against hydrogen content in Fig. 9. The two steels give graphs close together and the slight displacement may be attributed to a small change in the maximum stress of the samples.

Although differing methods of hydrogenation were used on specimens of different size, and the hydrogen content determined on different appliances, the agreement between the two sets of results is good and indicates that the method of hydrogenation has no effect on the results.

(iv) *Comparison of Samples from Forging with Rolled Bars*—Pieces of 3% Cr–Mo steel *H* were obtained in longitudinal, radial, and transverse directions from a large forging made from a 50-ton ingot. Transverse pieces were also obtained from a second forging (steel *I*) from a 95-ton ingot. The sawn pieces were all rough-turned to give cylinders 6 in. × 1 in. dia., and then oil-hardened from 900° C. and tempered at 660° C. for 1 hr., giving a maximum stress of about 55 tons/sq. in.

The heat-treated bars were machined into tensile test pieces of the usual type for use in the high-pressure apparatus. Hydrogen was added to each series at a number of levels and after fracture the hydrogen content of the whole test piece was determined (*see* Fig. 10).

Table V

HYDROGEN IN 3% Cr–Mo STEEL *B*. ELECTROLYTIC HYDROGENATION

Treatment	Hydrogen, ml./100 g.	Tensile Properties			
		Yield Point, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	Reduction in Area, %
As received	0·2	44·0	52·5	25·5	73·0
Heated in H_2, 2 hr. at 600° C., 1 atm.	0·7	44·0	52·0	25·0	71·5
Electrolyzed,* $7\frac{1}{2}$ hr., 2 amp. and $2\frac{1}{2}$ hr., 4 amp.	1·3	44·0	52·4	25·0	71·0
Electrolyzed, 96 hr., 4 amp.	6·0	44·0	51·8	19·5	51·5
Electrolyzed, 21 hr., 4 amp.	6·6	45·0	52·8	21·5	49·0
Electrolyzed, 24 hr., 6 amp.	7·4	45·0	53·2	20·0	48·0

* All electrolyzed in 2% H_2SO_4 at room temperature

Table VI

HYDROGEN IN 3% Cr–Mo STEEL *B*. HIGH-PRESSURE HYDROGENATION

Treatment	Hydrogen, ml./100 g.	Tensile Properties			
		Yield Point, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	Reduction in Area, %
As received	0·5	44·0	56·0	25·0	72·5
1 atm. H_2 at 600° C.	1·9	45·5	54·5	24·5	69·0
16 atm. H_2 at 600° C.	4·8	45·5	55·0	20·5	54·5
25 atm. H_2 at 600° C.	5·7	44·5	55·0	18·5	49·5
56 atm. H_2 at 600° C.	7·6	46·3	55·3	16·0	43·5
Electrolyzed*	3·7	46·0	55·3	22·0	54·5

* 40 hr., 4 amp. in 2% H_2SO_4

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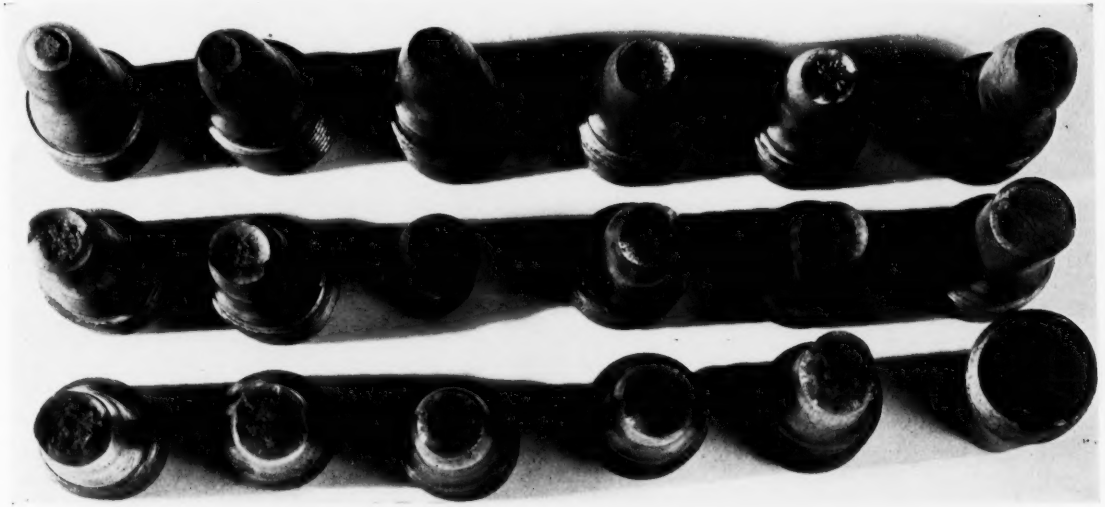

Fig. 6—Fractured tensile test pieces with differing hydrogen contents showing the effect of variation of maximum stress

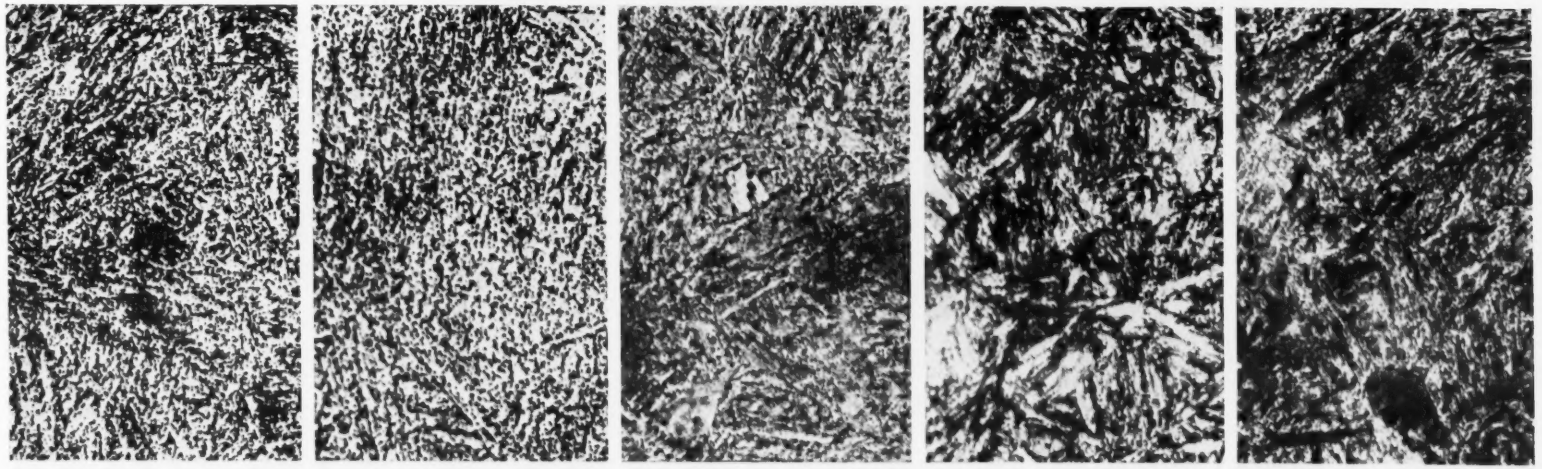

Fig. 7—Typical micro-structures of 3% Cr-Mo steel *B*, after heat treatment to give various values of maximum stress × 100

[*Hobson and Sykes*
[*To face p.* 214

Fig. 8—Fractured notched tensile test pieces with and without addition of hydrogen

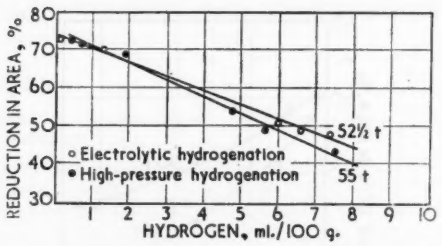

Fig. 9—Comparison of the effect of electrolytic and high-pressure hydrogenation of 3% Cr–Mo steel *B* on ductility as shown by percentage reduction in area

Although the longitudinal samples were only slightly inferior to bar material, those in the radial and transverse directions were inherently less ductile than longitudinal material, and a further loss in ductility was produced by the presence of hydrogen. The transverse tests on steel *I* were better than those obtained on steel *H*, but were still inferior to rolled bar and were also subject to hydrogen embrittlement. The radial and transverse specimens frequently exhibited a ' woody ' fracture, particularly in the presence of high concentrations of hydrogen.

3½% Nickel Steel

(i) *Comparison of Forged and Rolled Bar*—An ingot weighing about 5 cwt. was produced from a high-frequency cast of 3½% nickel steel (steel *K*). After discarding the head and bottom of the ingot, the remaining chill portion was split longitudinally, to give four quarters each about 2 ft. long × 3 in. sq.

One quarter was rolled to 1¼ in. dia. bar, and one quarter was forged to bar. Lengths of forged and rolled bar were turned to 1 in. dia. and then heat-treated to give 50 tons/sq. in. maximum stress by normalizing at 850° C., followed by tempering at 650° C. Tensile test pieces were turned from each material, and impregnated with hydrogen under pressure. Hydrogen was determined immediately after fracture.

Both materials had lowered ductility with increased hydrogen content (*see* Fig. 11) but there appears to be no significant difference in susceptibility to embrittlement.

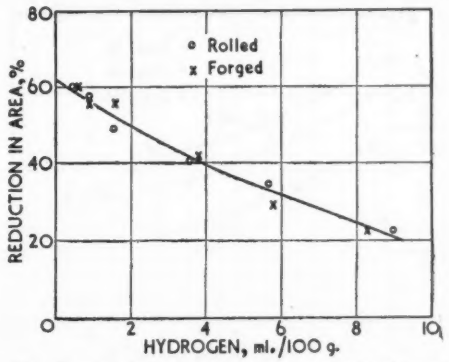

Fig. 11—Comparison of hydrogen embrittlement of rolled bar and forged bar of 3½% nickel steel *K*

An attempt was also made to include the ' as cast ' material in the series, but this experiment was unsuccessful owing to intergranular failure of the specimens.

(ii) *Experiments with Forged Steel*—Pieces were cut in longitudinal, radial, and transverse directions from a 3½% nickel steel forging (steel *L*) made from a 5-ton ingot. Bars of 1 in. dia. were normalized at 850° C., and tempered at 650° C. ; tensile test pieces prepared from these bars gave a maximum stress of 50 tons/sq. in. After impregnation with hydrogen at various pressures or de-hydrogenization in a vacuum furnace, they were tested and analysed for hydrogen in the usual manner.

The longitudinal test pieces gave results in good agreement with rolled bar material of the same type (*see* Fig. 12). The radial and transverse specimens had an inherently lower ductility, which was further reduced by increasing amounts of hydrogen.

FURTHER EXPERIMENTS ON FORGING STEELS

0·4% Carbon Steel

Figure 13 shows the results of three series of experiments using hydrogen-impregnated 0·4% carbon steel. The curve at 52 tons maximum stress was obtained with steel *M* taken longitudinally from a

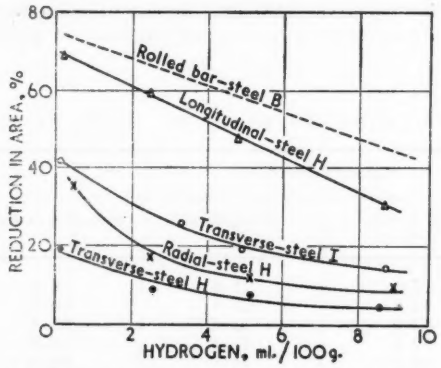

Fig. 10—Comparison of the hydrogen embrittlement of specimens cut in various directions from large forgings of 3% Cr–Mo steel

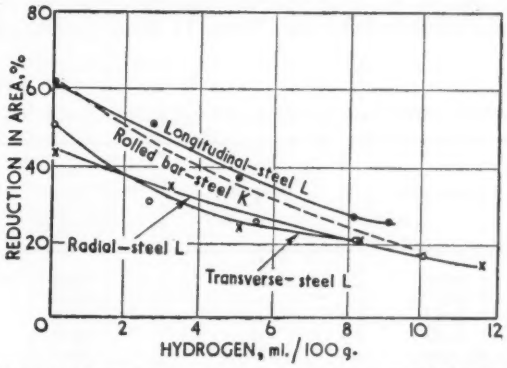

Fig. 12—Comparison of the hydrogen embrittlement of specimens cut in various directions from a large forging of 3½% nickel steel *L*

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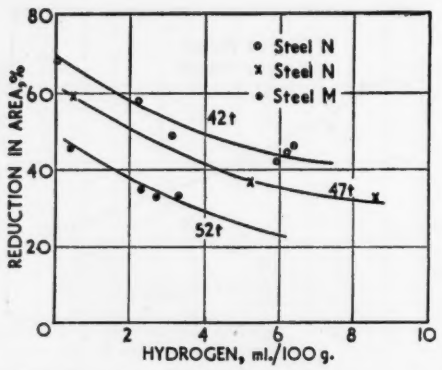

Fig. 13—Hydrogen embrittlement of two 0·4% carbon steels, showing the effect of variation of maximum stress

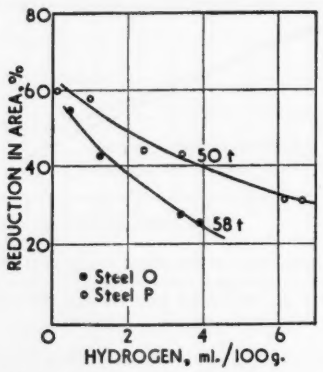

Fig. 14—Hydrogen embrittlement of two 1% nickel steels, showing the effect of variation of maximum stress

forging made from a 10-ton ingot. The test pieces were hardened from 850° C. and tempered at 400° C., and hydrogen was introduced by electrolysis.

The curves at 42 and 47 tons/sq. in. maximum stress were obtained on steel *N* about two years later, the hydrogen being added by the pressure method. The material was 1¼-in. rolled bar, and the pieces were oil-hardened from 850° C. and then tempered at 560° C. and 540° C. respectively.

As the maximum stress of the steel is raised by lowering the tempering temperature, the reduction in area at fracture is lowered. Further loss of ductility occurs, for each tonnage, as the hydrogen content of the steel increases. The results are self-consistent, although two methods of hydrogenation were used on different steels at widely separated times.

1% Nickel Steel

Two sets of specimens were cut longitudinally from 1% nickel steel forgings both made from 20-ton ingots. Steel *O* was water-quenched from 880° C. and then tempered at 555° C.; this gave a maximum stress of 58 tons/sq. in. This steel was charged with hydrogen by electrolysis in 2% sulphuric acid.

Steel *P* was water-quenched from 880° C. and tempered at 585° C.; this gave a maximum stress of 50 tons/sq. in. Hydrogen was then introduced by the high-pressure technique. Figure 14 shows the relation between hydrogen content and percentage reduction in area obtained on the tensile test; the curves follow the usual trend.

EFFECT OF HYDROGEN ON STRESS/STRAIN CURVES

Recovery of Ductility During Hydrogen Loss by Diffusion

Seven bars of 3% Cr–Mo steel *B* were heat-treated to give a maximum stress of 55 tons/sq. in. by oil hardening and tempering and were then turned to ¾ in. dia. Six bars were heated at 366 lb./sq. in. in hydrogen at 600° C. for 2 hr., thus introducing about 5 ml. hydrogen/100 g. These bars were allowed to stand at room temperature before being machined into tensile test pieces. The seventh bar was machined without hydrogen treatment.

The conventional mechanical test figures obtained are given in Table VII.

The ductility of the specimens steadily recovered as the increasing standing time allowed hydrogen to be lost by diffusion, and this is reflected in increased elongation and reduction in area at fracture. The percentage reductions in area for given quantities of hydrogen agree well with the values given in Fig. 9, although in the present experiment the hydrogen has been allowed to diffuse from the steel. The hydrogen figures after one and two days appear to be anomalous, but otherwise there is a steady increase in ductility

Table VII

RECOVERY OF DUCTILITY DURING LOSS OF HYDROGEN BY DIFFUSION—3% Cr–Mo STEEL *B*

Standing Period	Hydrogen, ml./100 g.	Tensile Properties			
		Yield Point, tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	Reduction in Area, %
1 hour	5·3	44·0	52·8	21·0	50·0
1 day	4·4	43·3	52·5	21·5	50·7
2 days	4·6	43·8	52·0	22·0	53·5
7 days	3·7	44·0	52·5	22·2	58·3
12 days	2·8	44·7	52·3	24·5	65·4
21 days	1·4	46·4	51·6	25·0	67·3
No H_2 added	0·1	45·0	51·8	27·5	73·5

and fall in hydrogen content as the standing period increases. Although the hydrogen content even after two days is up to 4·6 ml., no hair-line cracks were formed.

Change in Stress/Strain Curve during Hydrogen Diffusion

In testing the specimens in the above experiment, readings of diameter were made continuously so that the true strain could be determined. The stress/strain curve was then plotted by MacGregor's method.[10] He showed that the function

$$\text{True strain} = \log_{10}\left(\frac{\text{Original area}}{\text{Instantaneous area}}\right)$$

when plotted against

$$\text{True stress} = \frac{\text{Stress}}{\text{Instantaneous area}}$$

gave a straight-line plot during necking of the specimen.

Stress/strain curves were plotted in this way for each tensile test piece and it was found that the curves could be superimposed up to the point of fracture.

Necking of the test piece commenced at the end of the curved portion of the graph, and continued while the graph was linear, culminating eventually in fracture. It is apparent from Fig. 15 that the presence of hydrogen had little effect upon the stress/strain curve until the apparent maximum stress had been passed and necking was in progress. Similar conclusions have recently been reached as a result of the investigations of Herres.[11]

Increased hydrogen limits the formation of a neck and causes fracture before the true maximum stress is reached. This result is also implied by the observation that yield point and apparent maximum stress are almost independent of hydrogen content. There is a tendency for increasing hydrogen content to produce a slight increase in the *apparent* maximum stress, although the loss in ductility reduces the *true* maximum stress.

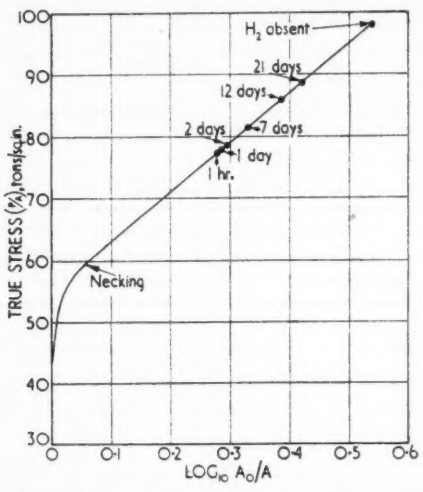

Fig. 15—True stress/strain curves for hydrogen-impregnated 3% Cr–Mo steel *B*, after standing in air for varying periods

Table VIII

DIMENSIONS OF NOTCHED TENSILE TESTS

Notch	Included Angle	Root Radius, in.	Shoulder dia., in.
A	90°	0·003$_5$	0·622
B	0°	0·042$_5$	0·622
C	0°	0·075	0·655
D	0°	0·125	0·755

Root dia. constant at 0·505 in.

Notched Tensile Test Pieces

Since the effect of hydrogen is largely to prevent or restrict necking it was decided to investigate its effect on tensile test pieces which had tri-axial stresses under load produced by a notch. Such stresses are likely to be found in forgings where they might arise from transformations, inclusions, or hair-line cracks.

A number of bars of 3% Cr–Mo steel *B* were hardened and tempered to 55 tons/sq. in. maximum stress and notches were cut in the centre of the parallel portion of a series of tensile test pieces (*see* Table VIII).

Test pieces were then fractured both with hydrogen treatment, which resulted in a content of 5 ml./100 g., and without. The reduction in area was followed continuously during the tests so that the stress/strain curves could be calculated (*see* Fig. 16). The fractured tensile test pieces (*see* Fig. 8) show the loss of ductility in the presence of hydrogen with a notch of large radius. The tensile test and hydrogen results are listed in Table IX.

The presence of increasingly sharp notches causes a curvature of the stress/strain curve and the presence of hydrogen leads to fracture at points earlier on the curves, as for the normal tensile test. With the sharp **V** notch, type *A*, hydrogen causes a slight lowering of the apparent maximum stress. The other notches were less sharp, being **U** shaped.

By using Neuber's diagrams,[12] it is possible to estimate the stress concentrations due to several of the notches, and these have been included in Table IX. The notched tensile test pieces have little advantage over the standard parallel type, in view of the practical difficulty of measuring accurately their percentage reduction in area and elongation. In the presence of very sharp notches, hydrogen present at about 5 ml./100 g., together with the high stress concentration,

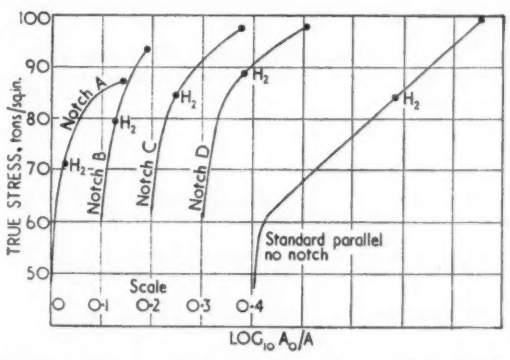

Fig. 16—True stress/strain curves for notched tensile test pieces of 3% Cr–Mo steel *B*. (Note—the origins of each curve have been displaced for clarity)

might suffice to cause brittle fracture at relatively low nominal stresses.

HYDROGEN AND THE NOTCHED-BAR IMPACT TEST

A number of experiments have been made to investigate the effect of hydrogen on notched-bar impact tests, and the results of these are as follows:

2½% Ni–Cr–Mo Steel

Samples cut in a transverse direction from a large 2½% Ni–Cr–Mo steel forging (steel *Q*) were machined into blanks for Charpy notched-bar impact tests. The specimens had a maximum stress of approximately 43 tons/sq. in.

Specimens were hydrogenated by cathodic electrolysis for varying periods and at a number of current densities and then rapidly notched and fractured at room temperature, 50° C., or 100° C. Hydrogen was immediately determined by vacuum heating (*see* Table X). The high value of 15 ml. hydrogen/100 g. obtained on one test piece shows the erratic nature of electrolytic hydrogenation.

There does not appear to be any significant change in impact value with hydrogen contents between 1 and 4 ml./100 g; indeed, in the range examined, the effect of temperature is of greater importance.

3% Cr–Mo Steel

In this series of tests, comparison was made between steel *J*, which was taken longitudinally from a large forging (35-ton ingot), and steel *E* in bar form. Specimens of each steel were tested after isothermal transformation (austenitized at 920° C. and transformed for 8 hr. at 690° C.) and also after air-hardening from 920° C., followed by 4 hr. tempering at 710° C., corresponding to a maximum stress of 44 tons/sq. in. in each case (*see* Table XI).

There is a general trend towards lower values after impregnation, but the most marked effects are at room temperature, for the isothermally treated steels, and at − 50° C., for steel *E* when hardened and tempered. It appears probable that hydrogen raises the transition temperature from the notch-brittle to the notch-ductile condition; this temperature, in the absence of hydrogen, is higher for the isothermal heat-treatment than the hardened and tempered condition, hence the temperatures at which the effects of hydrogen are most noticeable differ, *i.e.*, room tem-

Table IX

TENSILE PROPERTIES OF NOTCHED TENSILE TEST PIECES—3% Cr–Mo STEEL *B*

Notch	Hydrogen, ml./100 g.	Maximum Stress		Elongation, %	Reduction in Area, %	Calculated Stress Concentration
		On Original Area, tons/sq. in.	On Area at Fracture, tons/sq. in.			
A	Trace	70·6	87·2	*	28·8	6–7 approx.
A	5·9	67·2	71·2	*	6·0	6–7 ,,
B	Trace	77·4	98·1	7·8	27·1	2·35
B	5·6	75·0	86·1	3·3	13·3	2·35
C	Trace	75·6	113·2	9·4	43·8	1·93
C	5·5	75·9	88·6	3·9	14·6	1·93
D	Trace	74·8	110·9	6·7	45·0	1·63
D	5·0	77·5	94·1	3·9	15·8	1·63
Standard parallel	Trace	56·5	107·6	25·0	67·4	1·00
Standard parallel	5·3	55·0	81·8	21·0	50·0	1·00

* Note—Deformation at fracture prevented accurate location of the broken pieces

Table X

EFFECT OF HYDROGEN ON IMPACT VALUES OF 2½% Ni–Cr–Mo STEEL *Q*

Treatment of Steel		Hydrogen and Impact Results		
		At Room Temperature	At 50° C.	At 100° C.
As received	Hydrogen content, ml./100 g.	0·9	1·0	1·0
	Impact value, kg.m./sq.cm.	2·6	2·8	5·7
Hydrogenated	Hydrogen content, ml./100 g.	2·7	3·4	3·3
	Impact value, kg.m./sq.cm.	3·0	2·6	5·1
Hydrogenated	Hydrogen content, ml./100 g.	3·1	3·5	3·4
	Impact value, kg.m./sq.cm.	2·4	2·6	5·4
Hydrogenated	Hydrogen content, ml./100 g.	3·7	4·2	15·5
	Impact value, kg.m./sq.cm.	1·9	3·0	4·9

perature for the isothermally treated material and − 50° C. for the hardened and tempered material.

Whilst precautions were taken to prevent loss of hydrogen prior to testing, some was probably lost from the surface. Since the impact value depends a great deal on the initiation of the crack at the surface of the root of the notch where hydrogen loss would occur, the results recorded here may underestimate the effect of hydrogen on notch brittleness.

DISCUSSION AND CONCLUSIONS

These results confirm that there is a correlation between the ductility and hydrogen content of low-alloy steels. The design and operation of the high-pressure apparatus described in this paper allows hydrogenation of steel samples of sufficient size to enable the effects of hydrogen on the properties of the steel to be investigated, and hydrogen concentrations similar to those naturally present in commercial steels can be readily obtained.

Although there is some loss of notched-bar impact strength in steels containing hydrogen, the main effect of the gas is reflected in loss of ductility. Hydrogen has little effect on the shape of the tensile stress/strain curve, but results in fracture before elongation and necking reach normal values. Thus the true tensile stress calculated on the area at the point of fracture, neglecting tri-axial stresses due to the neck, is reduced by hydrogen, but since fracture usually occurs only after appreciable reduction of area, there is no effect upon the apparent maximum stress, calculated on the original area, which is normally reported.

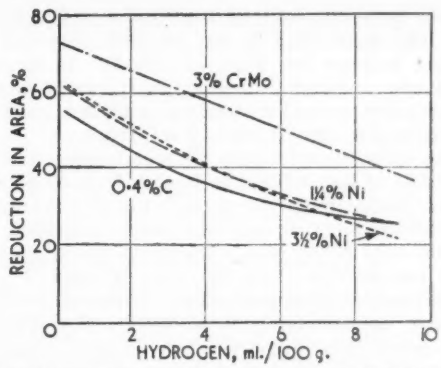

Fig. 17—Comparison of the hydrogen embrittlement of four forging steels when heat-treated to give a maximum stress of 50 tons/sq. in.

The results show that hydrogen introduced by electrolysis or by high-pressure treatment has the same effect. The diminution in reduction in area of different casts of the 3% Cr–Mo steel of the same tonnage shows that the magnitude of the embrittlement is remarkably consistent.

Bars produced by rolling or by forging and material cut longitudinally from large forgings all show similar embrittlement. The ductility of transverse and radial test pieces, which is often lower than that of longitudinal specimens, is decreased by the presence of hydrogen.

For small ruling sections (up to 6 in. dia.) the amount of hydrogen likely to be present in fully

Table XI

EFFECT OF HYDROGEN ON IMPACT PROPERTIES OF 3% Cr–Mo STEEL

Treatment	Steel *J* From Forging		Steel *E* From Bar	
	Hydrogen, ml./100 g.	Impact Value, kg.m./sq.cm.	Hydrogen, ml./100 g.	Impact Value, kg.m./sq.cm.
Isothermally Transformed				
Tested at − 50° C.				
Heated in vacuum	...	...	<0·1 <0·1	1·0 3·0
Heated in H_2	...	...	4·0 4·1	1·8 1·6
Tested at room temperature				
Heated in vacuum	<0·1 <0·1	11·0 15·6	<0·1 <0·1	12·2 8·8
Heated in H_2	4·5 4·6	4·4 8·2	3·4 3·5	5·4 5·7
Tested at 100° C.				
Heated in vacuum	<0·1 <0·1	21·0 19·3	<0·1 <0·1	17·9 17·6
Heated in H_2	4·1 4·0	18·6 18·3	3·5 4·0	15·9 15·6
Hardened and Tempered				
Tested at − 50° C.				
Heated in vacuum	...	...	<0·1 <0·1	23·6 23·5
Heated in H_2	...	...	3·6 3·4	14·9 11·6
Tested at room temperature				
Heated in vacuum	<0·1 <0·1	19·3 18·6	<0·1 <0·1	25·6 26·2
Heated in H_2	4·9 4·9	17·3 17·3	3·8 3·6	21·3 21·0
Tested at 100° C.				
Heated in vacuum	<0·1 <0·1	19·3 18·6	<0·1 <0·1	25·3 25·6
Heated in H_2	4·1 4·5	16·6 14·4	3·5 *	22·0 23·3

* Not determined

XUM

treated material, less than 1 ml./100 g., will not have any important effect on the ductility, even at the highest tonnage (*see* Figs. 4*a* and *b*). In forgings, transverse and radial ductility in the body may be significantly reduced if steps are not taken to reduce the hydrogen content below 2 ml./100 g.

The embrittlement data for four forging steels on the basis of longitudinal tests at a level of 50 tons/sq. in. tensile strength are given in Fig. 17. As regards the susceptibility to hair-line crack formation, the carbon steel is the least susceptible, the 3% Cr–Mo steel intermediate, and the 3½% Ni and 1% Ni similar and the most susceptible. With high hydrogen content, approximately 9 ml./100 g., the 3½% and 1% nickel show less reduction in area than the carbon steel, but at 2–4 ml./100 g., which is the level to be expected in forgings, the differences in actual reduction in area bear no relation to the hair-line-crack susceptibilities of the materials.

The transverse and radial figures for reduction in area obtained from test pieces cut from forgings corresponding to the excessive hydrogen contents of 9–10 ml./100 g. still appear adequate to prevent the completely brittle fracture typical of hair-line crack separations. Similarly, the remarkable consistency of the embrittling effects of hydrogen is in marked contrast to the erratic nature of the hair-line crack phenomena.

The previous heat-treatment of the steel plays an important part in determining the extent of embrittlement. The results obtained on 3% Cr–Mo steel suggest that there is an optimum tempering temperature which leaves susceptibility to hydrogen embrittlement at a minimum. Both hardened and spheroidized specimens are prone to embrittlement; the latter give highly ductile specimens only in the absence of hydrogen.

It seems that hydrogen content alone does not decide whether or not hair-line cracks will form. It does have an embrittling effect, particularly in the presence of stress raisers, which makes it desirable to adopt practical steelmaking and processing methods which give finished material with low hydrogen contents.

Acknowledgments

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Correspondence on the Paper—

METALLOGRAPHY OF ELECTRO-TINPLATE*

By J. E. Davies and W. E. Hoare

O. E. Romig and Associates (United States Steel Company, Pittsburgh): The mounting procedure used by the authors is a practical modification of one that has been used occasionally in our own laboratory. The polishing procedure is novel and should be worthy of further development, and the technique used to determine the extent of attack by the detinning process, although not new, appears to be effective. The photomicrographs are convincing: the formation of the rectangular areas that are clearly visible in or on the surface of the alloy layer in Figs. 12 and 18 is remarkable. The authors are undoubtedly correct in postulating that the geometrical arrangement of these areas is associated with the crystal structure of the grains in the steel. However, the fact that these areas become smaller and almost unresolvable as the alloy layer grows is unexpected. The authors have been able to distinguish $FeSn_2$ and FeSn by the use of polarized light, and it is hoped that this observation can be confirmed by X-ray work or by other means of identification.

From our experience with the use of oblique sectioning, we have found it very difficult to study pores without being misled by flowed metal caused by polishing. We have never observed that the iron–tin alloy is continuous. This conclusion is drawn from the results of 90° microscopic work and from the results of porosity tests made by chemical methods.

Further evidence to support some of the authors' conclusions would be a welcome addition to this very interesting paper.

**Journal of The Iron and Steel Institute*, 1951, vol. 168, pp. 134–140.

A Simple Reflecting Microscope for High-Temperature Metallography

By D. W. Dewhirst, M.A., and M. J. Olney, B.Sc.

SYNOPSIS

Various types of microscope objective of unconventional design, and of possible value to the metallurgist, are described.

Special reference is made to systems capable of giving high magnification but with large working distance, suitable for high-temperature metallography. A detailed description of the design, construction, and adjustment of a simple reflecting microscope with a bi-spherical monocentric objective of 0·5 N.A. and 17 mm. working distance is given, with information on photographic techniques. A complete apparatus for the examination of specimens *in vacuo* at temperatures up to 1000° C., and some typical results obtained by its use, are described.

Introduction

In most metals, the dynamic processes of recrystallization, grain growth, and precipitation occur readily only at elevated temperatures. A metallographic study of a particular phase is often impossible because the phase is stable only at high temperatures and undergoes transformation on cooling, so that only the decomposition products are available for study. It is therefore desirable to be able to study metallographic specimens at elevated temperatures with the microscope.

As early as 1912 Robin[1] described the use of a refracting microscope for the examination of heated metal specimens. Other workers have published observations on transformations in pure metals and iron alloys,[2] and on the iron–carbon diagram and the solubility of oxygen in solid iron.[3] More recently, Nickols[4] has given details of a vacuum furnace for high-temperature microscopy.

The resolution of an objective is defined by $\lambda/kn\sin u$ where λ is the wavelength of the light, n is the refractive index of the medium between the object and the objective, u is the half-angle subtended by the objective aperture at the axial object point, and k is a constant of value about 2·0 (*see* Fig. 1). The factor $n\sin u$ is the *numerical aperture* (N.A.) of the objective, and is the most important factor in characterizing its performance, finer detail being revealed as the N.A. increases. The limit to the performance of a well-designed objective is set by its N.A.; for the normal eye with green light a magnification of about 1000 for every unit of N.A. will show all the detail that the objective is capable of resolving. The 'working distance' is also important when the specimen is at an elevated temperature, as the delicate lens system will be damaged if it is too close to the specimen. Unfortunately, the working distance and N.A. of refracting objectives are inversely related quantities, so that with high magnifications the objective is necessarily close to the specimen—a disadvantage of the compound refracting microscope. Thus a typical modern 32-mm. objective of 0·15 N.A. has a working distance of 22·5 mm., but an 8-mm. 0·5 N.A. objective has a working distance of only 1·5 mm.[5]

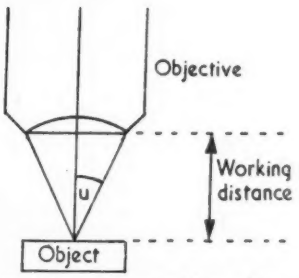

Fig. 1—Numerical aperture and working distance of an objective

Using conventional microscopes for high-temperature metallography, previous investigators have attained useful magnifications of × 200 maximum, and although in some preliminary experiments the present authors were able to use an objective of about 0·3 N.A. in conjunction with a vacuum furnace described later in the present paper, it appeared that the limit had been reached. Alternative systems with greater working distance were therefore investigated.

AVAILABLE SYSTEMS*

Considerable interest has recently been shown in objectives that permit higher useful magnification whilst retaining a large working distance. The optical systems that have been described, which permit an alteration of some of the characteristic properties of conventional refracting objectives, may be classified into five groups:

(*A*) Modified (*e.g.*, scaled-up) conventional objectives.
(*B*) Reflecting objectives consisting of a combination containing aspherical mirrors, or, for lower numerical apertures, a combination of spherical mirrors.
(*C*) Primarily reflecting objectives with spherical mirrors, but with additional zero- or low-power lenses to correct aberrations.

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* For the sake of completeness, reference has been made in this survey of the literature to related systems which, whilst not characterized by large working distance, might be of value in other metallographic investigations.

(*D*) Catadioptric systems in which both reflection and refraction contribute appreciably to the convergence of light.

(*E*) Unit- or low-magnification systems of high working distance, which produce a real image of the object for examination by a conventional microscope.

(*A*) *Modified Objectives*—In metallographic experiments at elevated temperatures, Robin[1] introduced an achromatic concave lens between the objective and the eyepiece of a conventional microscope : this served to increase the working distance without substantially altering the initial magnification and mechanical tube length of a normal microscope, and with less serious effect on the aberrations of the image ; but the effective N.A. was reduced. Any attempt to increase the working distance whilst maintaining a high N.A. and the standard tube length meets with the difficulty that the curves of the lens surfaces become very steep and the necessary corrections are not attainable.

Another method is to scale up linearly a normal refracting objective, increasing in proportion the working distance and tube length, whilst retaining the N.A. and initial magnification, but in the simplest case the aberrations are also scaled up linearly. The British Scientific Instrument Research Association has recently computed a scaled-up objective which, although based on a 4-mm. objective design, has been altered slightly to improve the aberrations, and it has been constructed for the Royal Aircraft Establishment, Farnborough.[6] No similar systems appear to have been constructed elsewhere.

(*B*) *Reflecting Objectives*—Newton was the first to recognize the advantages of a concave mirror as an alternative to the single convex lens then used as a microscope objective, and reflecting objectives of various designs were widely used in the 18th and 19th centuries. They became obsolete when the achromatic refracting objective was developed commercially and subsequently rapidly improved. The numerous advantages peculiar to fully reflecting systems—perfect achromatism, absence of absorption in the ultra-violet and infra-red regions of the spectrum, and in many instances high working distance—have led, however, to their revival in recent years.

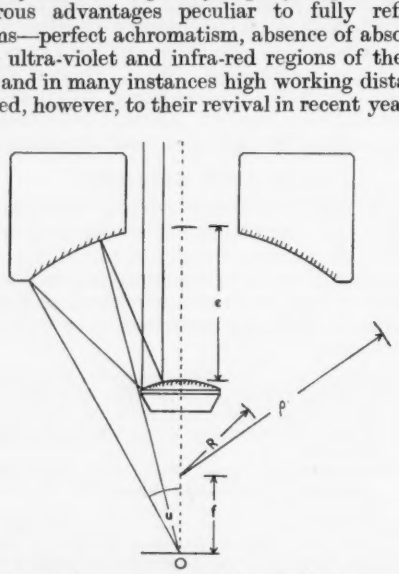


Fig. 2—Optical components of bi-spherical monocentric objective of 0·5 N.A.

The theory of the two-mirror image-forming system was first developed in the classical work of Schwarzschild.[7] Although he considered especially the design of aplanatic two-mirror telescope systems, the principles of his analysis are generally applicable. Many of Schwarzschild's results were discovered independently by Chrétien in 1922.[8] Maksutov, in Russia, and Burch, in this country, were the first to consider specifically the theory of microscope systems.

Maksutov, apparently unaware of the work of Schwarzschild and Chrétien, showed that a mirror pair (of the general Schwarzschild type, illustrated in Fig. 2) with one mirror spherical and the other a cardioid, could be used as an aplanatic objective. He also constructed a ' solid ' glass objective of similar design.[9]

About 1934, Burch applied the Schwarzschild analysis to microscope systems, and by 1938 had completed an objective with both mirrors aspherical : it was of 0·58 N.A. (and, when used in conjunction with a refracting immersion component, 0·98 N.A.). Burch also investigated the Seidel aberrations of aspherical lenses and mirror combinations, deriving in one paper[10] the conditions for astigmatism of a mirror pair, and in a later one[11] the conditions for Seidel field-flatness with some general formulae relating to Schwarzschild systems. The same author later reviewed[12] the historical development of the reflecting microscope, and surveyed the theory from the designer's point of view : the two above-mentioned objectives were described, and some formulae for constructing systems with various characteristics were given. In an appended paper values were derived for the aberrations, and the limitations of systems with one mirror spherical were discussed. More recently, Drew[13] has described ' solid ' objectives of quartz, with one of two reflecting surfaces aspherical.

All Schwarzschild systems can have a high working distance and are very suitable for high-temperature microscopy. Unfortunately, the aspherized surfaces required are very difficult to produce, and they are unlikely to be widely available for some years.

(*C*) *Spherical Mirrors with Correcting Lenses*—A single concave spherical mirror can be used as a microscope objective, but the object and image spaces are on the same side of a single reflecting surface, with consequent mechanical difficulties in design. The defects in the image produced by a single spherical mirror can be largely corrected by placing a low-power lens (or occasionally lenses) in the optical system. These correcting lenses may be either aspherical correcting plates of the Schmidt type or concentric-meniscus lenses of the type first described by Maksutov[14] and which have been used by other workers in this country.[15, 16] The meniscus lenses are easier to produce because both surfaces are spherical.

Linfoot[17] has described a spherical mirror with the object slightly inside the focal point, giving a real inverted image with a high primary magnification ; spherical aberration is corrected by a Schmidt-type aspherical plate of minimized thickness, approximately at the centre of curvature of the mirror. In its simplest form this type therefore has the object situated between the mirror and the correcting plate. (Fig. 3*a*). An essentially similar system has been

described by Bouwers[18] (Fig. 3*b*), but here the correcting lens is an achromatized meniscus of the Maksutov type. A centrally pierced, oblique, flat mirror between the object and spherical mirror reflects the image beam to one side. Microscopes of this form are now being made commercially in Holland, and are available in this country. They are of 0·2 N.A., although it is understood that systems of higher N.A. are being developed.

Johnson[19] has developed various forms of single-mirror objectives with a 'Mangin'-type mirror, *i.e.*, a back-silvered concavo-meniscus lens, which is, in effect, a spherical concave mirror with a meniscus correcting lens immediately in front of it (Fig. 3*c*). The first form was described in 1934,[20] and a simplified form in 1942, when the advantage of these systems for the examination of opaque objects was also pointed out.[21] (Immersion systems of up to 1·27 N.A. have been described.[22])

In systems of this type, where the refraction is small, the achromatic property of the reflecting objectives is largely retained, and so is the transmission if suitable lens materials (*e.g.*, quartz, fluorite or lithium fluoride) are chosen. In general, the mechanical working distance of the single-mirror types is greater than that of the equivalent refracting objectives but, because it is less than the 'optical' working distance, by reason of the reflecting flat that must be introduced between the object and mirror to divert either the image space (Bouwers) or the object space (Johnson), it is capable of only limited improvement.

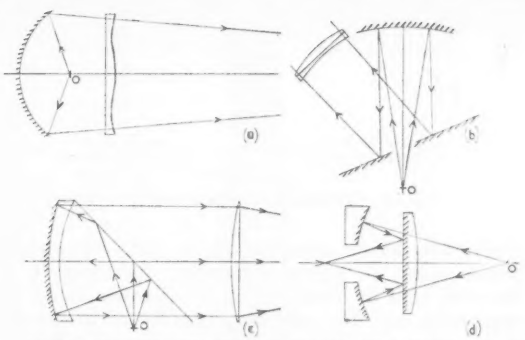
Theoretically it is also possible to use zero- or low-power correcting lenses to reduce the aberrations of a Schwarzschild objective with two spherical mirrors, and this method has been discussed by Grey and Lee,[23] although no simple objectives of this type appear to have been constructed.

(*D*) *Catadioptric Systems*—In a series of papers Grey and Lee are considering morphologically the various optical systems suitable for microscope objectives. The first two papers[23] describe systems based on Newtonian and Schwarzschild principles, respectively.

To make the objectives suitable for commercial production, these writers have eliminated from the designs : (1) aspherical surfaces, (2) partially silvered surfaces, (3) refracting media other than the simple glasses, quartz, and fluorite.

Some of the various systems referred to elsewhere in the present paper are briefly described. Grey and Lee have also designed catadioptric objectives of some complexity in which convergence is produced both by reflecting and achromatized refracting components : similar systems have also been designed for use with ultra-violet illumination.[24] A closer approach to achromatism than in conventional refracting objectives is claimed, with some advantages over the more delicate reflecting objectives. Some of these systems are now being produced commercially in America and would appear to have working distances a little larger than those of equivalent refracting objectives.

(*E*) *Unit- or Low-Magnification Systems*—Dyson[25] has preferred to use for high-temperature microscopy a unit-magnification system of large working distance. The system produces a real image of the object which is examined with a conventional microscope (Fig. 3*d*). Fully refracting systems of the high degree of correction necessary are not feasible.



(*a*) Aspherical correcting plate of Schmidt type. Object between spherical mirror and plate
(*b*) Achromatized meniscus of Maksutov type as corrector. Oblique flat mirror between object and spherical mirror
(*c*) Mangin-type mirror with both surfaces spherical
(*d*) Unit-magnification system for use with conventional microscope

Fig.—3. Reflecting objectives

The specimen is at the centre of curvature of a spherical mirror, the image is therefore coincident with the object and free from spherical aberration. A half-silvered flat is placed mid-way between mirror and object, and an image of unit magnification is formed at the axial point of the concave mirror, which is centrally pierced. Spherical aberration is introduced by the finite thickness of the flat, and also by a plane-parallel furnace window, and is corrected by making the unsilvered surface of the flat slightly convex. A simple theoretical treatment of the aberrations has been given, and solid immersion units have been designed for nuclear plate and biological work.[26] More complete corrections can be obtained by using additional concentric-meniscus lenses in the viewing microscope ; the lenses are placed at the image of the position which they would occupy if they could be placed conveniently in the unit-magnification system.[26] The use of a solid immersion component as an interferometer microscope has also been described.[27] A simple unit-magnification system of large working distance for use in conjunction with an ordinary microscope is now being produced commercially in this country.

A similar unit has been developed by Heal[28] of the British Iron and Steel Research Association. This is a solid unit-magnification objective with the first glass/air surface spherical and concentric with the axial object point.

Because of the partially reflecting surfaces, these systems require carefully designed illuminating devices for the examination of opaque objects under bright field illumination, or must be used with dark field illumination. An alternative to partially reflecting silvered surfaces has been suggested by Grey and Lee[23] who have substituted for them alternate fully transmitting and reflecting concentric annuli.

THE BI-SPHERICAL REFLECTING MICROSCOPE

The type of objective with which this paper is especially concerned is a special case of the Schwarz-

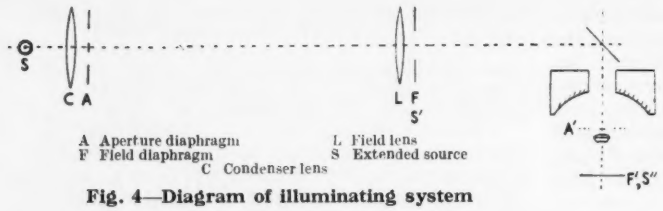


Fig. 4—Diagram of illuminating system

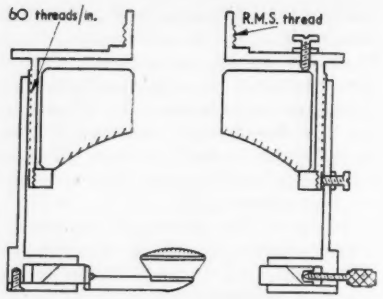


Fig. 5—Diagram of objective mounting

schild two-mirror objective (*see* p. 222). For good performance at higher numerical apertures it is essential that at least one of the mirrors should be aspherical, and the extreme difficulty of producing such surfaces has already been emphasized. Burch, however, has shown[12] that, up to 0·5 N.A. and with suitable design, Schwarzschild systems with two spherical mirrors can give satisfactory performance and present no difficulties in manufacture.

Hershgorin[29] appears to have been the first to construct such objectives, which have been used by Brumberg for the examination of silver in polished ore sections,[30] and for biological investigations,[31] using ultra-violet light. American investigators have also used a bi-spherical reflecting objective of 0·3 N.A. and 16 mm. focal length for phase-contrast microscopy in the ultra-violet range.[32] In this country, Seeds and Wilkins[33] have given details of a small bi-spherical objective of 0·5 N.A. and 5 mm. focal length for ultra-violet biological work.

The bi-spherical reflecting objective permits a considerable increase in working distance with the minimum of optical surfaces, and is simple in design and manufacture. It thus appeared to the authors to be the most suitable for the problem under investigation. Moreover, since only surface-silvered mirrors are involved, the two optical components can be of low-expansion glass or fused quartz without the optical homogeneity required for transmission components. The fully reflecting surfaces minimize heat absorption.

The relevant data for a monocentric two-mirror system have been given by Burch in the papers quoted earlier. If the concave and convex mirrors are of radius ρ and R respectively, and their axial separation is ε, then parallel light falling on the convex mirror is imaged at O, a distance m from the pole of the concave mirror (Fig. 2). With both mirrors spherical, the system becomes monocentric and anastigmatic, when $\varepsilon = 2$, $m = 2 + \sqrt{5}$, $\rho = \sqrt{5} + 1$, and $R = \sqrt{5} - 1$ in units of focal length.

The linear obstruction of the concave mirror by the convex secondary is $1/(m - \varepsilon) = 1/\sqrt{5}$ or 44·7%; this large central obstruction in the image-forming cone is the greatest disadvantage of the bi-spherical monocentric objective. The actual loss of light is not serious, but the central stop results in a redistribution of light in the diffraction pattern which the objective produces as the image of a point source. The stop reduces the diameter of the central bright spot, thereby increasing the resolving power slightly, but throws more light into the diffraction rings, especially into the first ring, which results in a loss of contrast. The general result is not so much an improvement or deterioration in the quality of the image, but an alteration in its intrinsic nature which, depending on the nature of the specimen, may or may not be desirable. In a short note giving some dimensions for reflecting microscope systems of various obstruction ratios Burch[34] has discussed the effect of this central obstruction on the quality of the image.

For most metallurgical work a small obstruction ratio is to be preferred. After the objective described in the present paper was completed, Seeds and Wilkins[33] reported that for their purposes they had obtained improved results with bi-spherical objectives in which the N.A. was increased and the obstruction ratio reduced. The present authors have not constructed such systems, but it is probable that some improvement in the quality of the image could be obtained without a great reduction of the working distance. Small reflecting objectives based on these modified designs are now available commercially in this country.

For the examination of metallographic specimens at elevated temperatures, which must be *in vacuo* or in an inert atmosphere, it is necessary to introduce a plane-parallel glass or quartz furnace window between the specimen and the objective. This introduces spherical aberration, which can mainly be removed by a slight alteration in the separation of the two mirrors. Chromatic aberration is also introduced but is usually negligible, although it can be removed by a low-power convergent lens in the image space.[35] To minimize both spherical and chromatic aberration the furnace window should be no thicker than is necessary to support atmospheric pressure.

For satisfactory performance the tube length of reflecting microscopes of this kind should not be too short, and the objectives can usefully have a primary magnification greater than that of refracting objectives of equivalent N.A.

Illumination

The simple reflecting objective does not present any difficulties in the bright field illumination of metallurgical specimens, and is in fact superior to the conventional objective because there are no unwanted reflections from glass/air interfaces. A normal arrangement for critical illumination can be used in conjunction with a 45° reflector (as in Fig. 4). The condenser lens C forms an image of an extended source S on the field diaphragm F, which is in turn imaged on the specimen by the objective. The only additional requirement is a patch stop in the centre of

the aperture diaphragm A whose image is formed slightly above the convex secondary by the usual lens L. This prevents light being reflected directly into the field of view by the unused central portion of the secondary.

DETAILS OF CONSTRUCTION

Objective

The dimensions of the bi-spherical monocentric objective (*see* Fig. 2) constructed by the authors are as follows :

R	13·33 mm.
ρ	35·00* ,,
f	10·80 ,,
$\epsilon = \rho - R$	21·67 ,,
$m = \rho + f$	45·81 ,,
$f/(m - \epsilon)$	44·8%
R/ρ	1/2·625
N.A.	0·5
u	30°

* This deviates very slightly from the condition quoted in the text in order to simplify manufacture.

Primary :	
Clear aperture	44·00 mm.
Ext. diam.	49·00 ,,
Exit hole	16·00 ,,
Thickness at edge	18·00 ,,
Secondary :	
Clear aperture	11·35 ,,
Rim depth	0·50 ,,
Axial thickness t	4·30 ,,
Working distance $(R + f - t)$	19·80 ,,
,, ,, (mechanical)	17·0 ,,

The primary mirror is of Pyrex and the secondary of fused quartz. Both mirrors are spherical to within $\frac{1}{4}\lambda$ and are surface aluminized to withstand slight temperature changes. Non-optical surfaces are smoothed and the edges bevelled.

The design of the brass mounting for the mirrors is shown in Fig. 5. The primary mirror is mounted in a housing, which is lined with a lightly piled cloth so that the mirror is a close, but not tight, fit. Three 8 B.A. screws with locknuts hold the mirror lightly in place against the lower projecting ring, which is screwed in when the mirror is in place. The bottom part of the mounting, carrying the secondary, screws on to the top housing by means of a fine thread (60 threads/in.), thus affording a precise means of adjusting the separation of the mirrors. When the objective has been adjusted, further movement of the components is prevented by tightening three screws (one of which is shown in Fig. 5). The secondary mirror is fastened to a small circular platform with low-melting-point wax, the platform being soldered to the end of a thin arm projecting radially inwards from a brass ring. This ring is free to move laterally between accurately machined faces and is both moved and fixed in any desired position by three screws with knurled heads. These screws bear upon the bevelled circumference of the ring *via* 45° wedges, thus ensuring that the ring carrying the small mirror is always in contact with the lower bearing surface.

Microscope and Stand

The microscope body is based on that of a standard metallurgical model, but the tube length has been increased by means of brass extension pieces. The block containing the coarse and fine focusing attachments is mounted on a brass ring in such a way that the optical axis of the microscope is coincident with the axis of the ring. This ring carrying the microscope is supported in a recess in a larger brass ring, in which it is free to move horizontally approximately $\frac{1}{4}$ in. in any direction. It is positioned and clamped by three screws around the circumference acting radially at 120°.

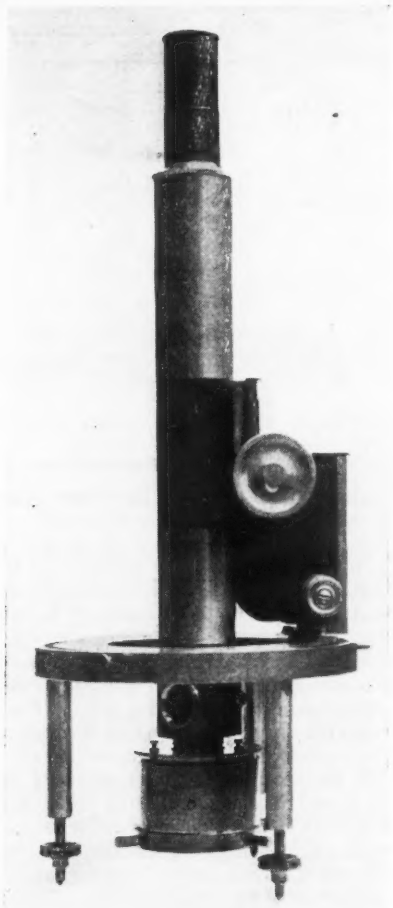


Fig. 6—Microscope and stand with illuminator and reflecting objective in position

The larger ring carries on its underside three threaded brass collars, into which fit adjustable screwed legs with domed ends. These legs are located kinematically on the furnace lid in a depression, a vee-slot, and on the plane surface. The general construction of the microscope is shown in Fig. 6, with the reflecting objective and vertical illuminator in position. The plane glass reflector must be a little larger than that in the conventional microscope because of the greater diameter of the emergent cone immediately above the objective.

Design of Vacuum Furnace

A sectional view of the vacuum furnace in which the specimen is heated during examination is shown in Fig. 7. This was developed independently by one

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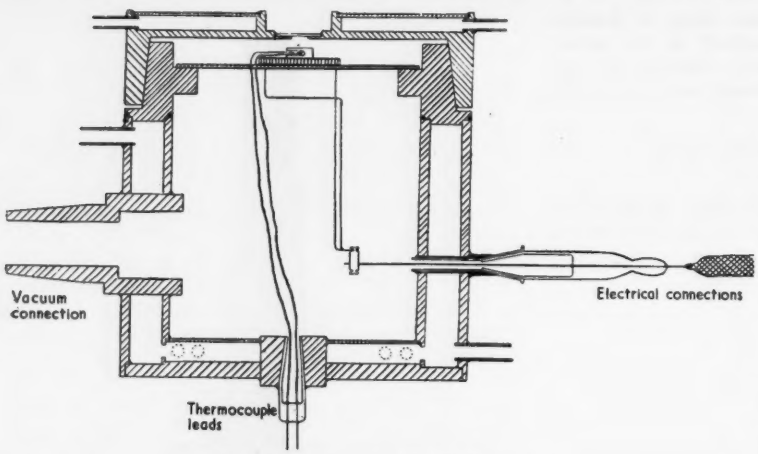


Fig. 7—Sectional view of furnace

of the authors (M.J.O.), but has some features in common with that described by Nickols.[4]

The heating element consists of a thin alumina plate $1\frac{1}{4}$ in. sq. and $\frac{1}{8}$ in. thick wound with 0·016 in. dia. tungsten wire, and has a resistance when cold of approximately 5 ohms. After winding, the plate was covered on the top and bottom with alumina cement to protect and insulate the wire. It rests upon a triangle of stout tungsten wire, which is supported by a projecting ledge on the furnace body. The current from a variable transformer is led in through tungsten electrodes sealed into Pyrex glass cones, and a Pt/Pt–Rh thermocouple for temperature measurements is sealed into a glass cone, which fits into a tapered hole in the bottom of the furnace.

The removable lid fits the furnace body by means of a machined brass taper, silicone high-vacuum grease being used to effect the seal. The window, which is 1·5 mm. thick and of optical quality fused quartz, is sealed into a recess in the furnace lid with picene wax.

The furnace and lid are hollow and are cooled by circulating water. A vacuum better than 10^{-4} mm. Hg is maintained in the furnace by an oil-diffusion pump : the system also includes two liquid air traps, and a McLeod gauge for pressure measurements.

EXPERIMENTAL DETAILS

Initial Adjustment of Objective

The furnace window introduces spherical aberration, which can be largely corrected by a slight adjustment of the objective. To adjust the objective for the chosen tube length and furnace window, the microscope is fitted with a high-power eyepiece (× 25) of the Ramsden type, the focal plane of which is coincident with the required position of the primary image. A suitable 'star test' object (*e.g.*, a small illuminated mercury droplet) is viewed with the microscope ; the point source is almost brought to focus and the objective adjusted until

(i) The diffraction pattern is a series of concentric and uniformly bright circular rings (by centring the secondary mirror)

(ii) The diffraction pattern has the same appearance at small equal distances on each side of the focus (by adjusting the separation of the components).

If the optic axis of the primary does not coincide with the mechanical axis of the objective it is necessary to complete the adjustment by successive repetitions of the above operations.

Operation

The thermocouple, protected by a thin platinum sheath, is inserted in a hole drilled in the side of the specimen, which is placed on the heating plate. The lid is placed in position and the system evacuated. The microscope, after being positioned on the furnace lid, is brought normal to the surface of the specimen and the illumination is finally adjusted. Care must be taken that the surface of the specimen is parallel to the furnace window. Heating of the specimen is commenced as soon as the pressure is reduced to 5×10^{-6} mm. Hg. Some metallographic features on the specimen become visible by the occurrence of thermal etching ; details of this phenomenon have been given by other investigators.[36]

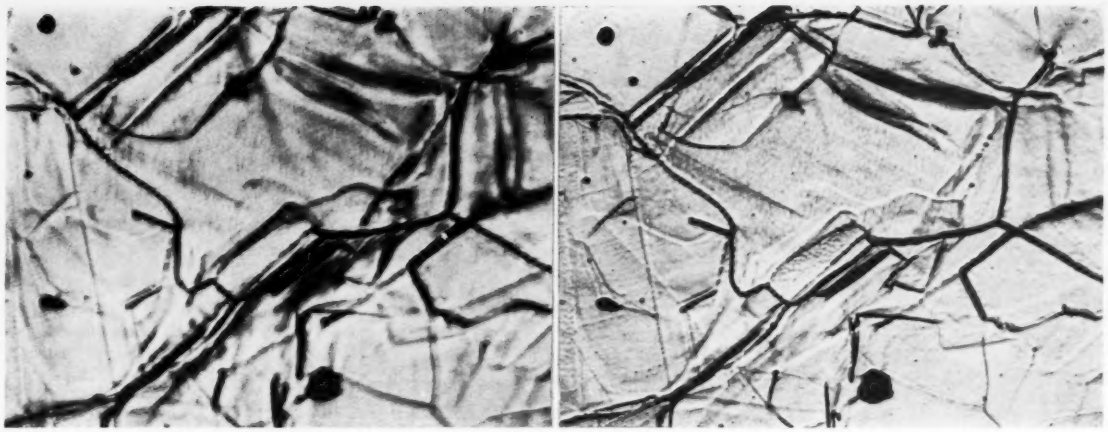
Photographic Technique

Two methods are available for taking photomicrographs : the primary image may be directly recorded and subsequently enlarged, or an enlarged image produced by a suitable eyepiece may be recorded.

The latter method is desirable with conventional microscopes partly because the primary magnification of the objective is low and also because a suitably designed eyepiece can further correct some of the errors of the objective. The authors, however, use the former method, which has many advantages with the reflecting microscope. The objective performs better when the tube length is large and the primary magnification high : also much of the advantage of achromatism and full 'transmission' peculiar to the reflecting system is lost if a refracting component is introduced. In any event, ordinary microscope eyepieces are not well suited for use with a reflecting objective.

As the photographic plate will usually be enlarged considerably to produce the final photograph, a plate with a fine-grained emulsion, followed by suitable development, is essential. When the specimen is at an elevated temperature the intensity of red light emitted is considerable and if a panchromatic plate is used not only is contrast lost, but the exposure required varies both with the temperature and with the nature of the specimen, which introduces difficulty if exposures have to be made in rapid succession. It has been found simplest to illuminate the specimen with blue light and to use a fine-grained, orthochromatic emulsion.

As first constructed (Fig. 6), the microscope had a tube length of 35 cm., giving a primary magnification



(a) Photographed cold, using reflecting objective of 0·5 N.A. through quartz window. Working distance 17·0 mm.

(b) Photographed under ideal conditions, using refracting objective of equivalent N.A. on standard metallograph. Working distance 2·0 mm.

Fig. 8—Micrographs of pure iron, thermally etched × 500

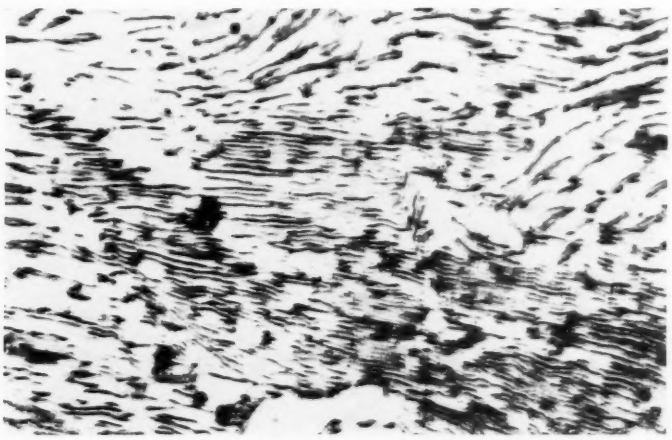
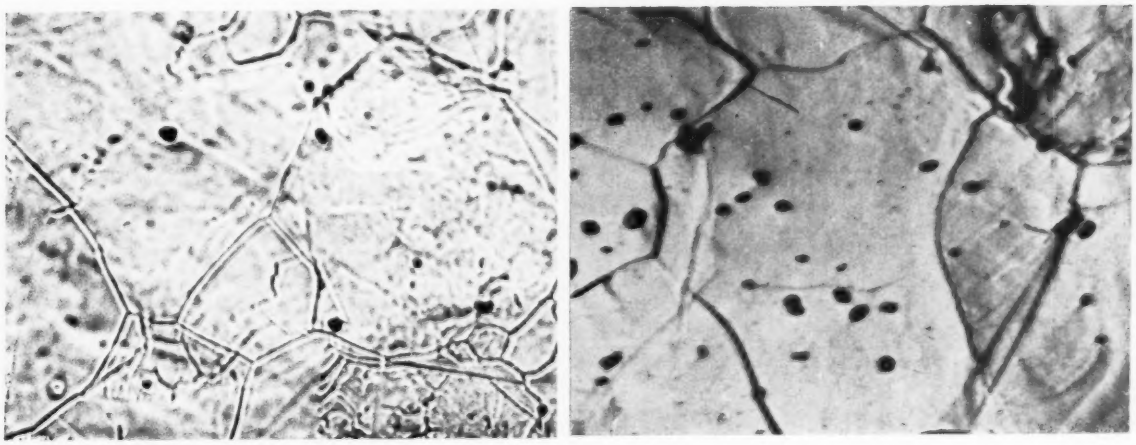


Fig. 9—Resolution test on lamellar pearlite with reflecting objective × 750



(a) 1·17 per cent. steel after ½ hr. at 950° C *in vacuo*

(b) Pure iron after 15 mins. at 745° C. *in vacuo*

Fig. 10—Specimens photographed whilst heated, using reflecting objective × 350

[*Dewhirst and Olney*

[*To face p.* 226

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of 33·5. Although satisfactory results can be obtained with this arrangement, the choice of plate and conditions of exposure and development are less critical when the primary magnification is somewhat greater.

The tube length has therefore been increased to give a primary magnification of 55. In addition, a simple plate holder at the prime focus, which was first used, has now been replaced by a 35-mm. camera (with the lens removed) thus permitting up to 40 exposures to be made in rapid succession. A viewing eyepiece fitted with a graticule parfocal with the film plane can be interposed in the optic axis of the microscope, thus permitting visual examination or adjustment of focus during the course of an experiment.

With this arrangement, adaptation for cinephotomicrographic work presents few difficulties.

Results

A detailed account of some results obtained with this apparatus will be published later,[37] but the accompanying photomicrographs (Figs. 8 to 10) illustrate its capabilities.

That the performance of the objective is satisfactory can be seen by comparing Figs. 8*a* and *b*, which are photomicrographs at room temperature of a specimen of spectroscopically pure iron (containing, however, oxide inclusions), after mechanical polishing followed by thermal etching.

Figure 8*a* is taken with the reflecting microscope, the specimen being in position in the furnace, whilst Fig. 8*b* is taken under ideal conditions with an objective of equivalent N.A. on a research metallograph.

Tests on lamellar pearlite (Fig. 9) have shown that the resolution of the objective closely approaches the expected value, the original photograph showing as separated platelets of cementite 0·75 μ apart.

Figure 10*a* shows austenite grains in a hypereutectoid steel at 950° C., and Fig. 10*b* shows ferrite grains in pure iron at 745° C.

It seems that the optical performance of the system is not impaired up to 1000° C., the highest temperature so far used.

One difficulty of the technique, which does not appear to have been reported by other investigators, is that at very elevated temperatures in high vacua metal evaporated from the specimen may condense on the underside of the window. This has been overcome by placing immediately above the specimen a disc of tantalum foil centrally pierced with a hole which, whilst small, still permits a considerable area of the specimen to be brought under examination.

Acknowledgments

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Electrochemical Studies of Protective Coatings on Metals

By F. Wormwell, M.Sc., Ph.D., and D. M. Brasher, B.Sc., A.R.I.C.

PART III—THE CORRELATION BETWEEN CONDUCTANCE OR CAPACITANCE AND AREA OF BREAKDOWN OF PAINT ON STEEL IMMERSED IN SEA WATER

SYNOPSIS

The electrical conductance or capacitance of a pair of painted metal plates immersed in an electrolyte is not directly proportional to the area of paint breakdown because of (1) the spreading in the electrolyte of the 'lines of conduction' between exposed areas, (2) the effect of the thickness of the rust deposit. By observing certain precautions an approximate estimate of the area of breakdown can nevertheless be obtained and hence the method may prove useful when the area is too ill-defined to be measured visually.

For the paints and conditions investigated, the rate of penetration of corrosion at exposed areas is independent of the relative areas of exposed metal and of intact paint film. This suggests that no appreciable cathodic action occurs on the areas of intact paint.

It has been shown in Part II[1] of the present series of papers that the incidence of paint failure on steel plates immersed in sea water can be detected readily and reliably by measurements of conductance and capacitance. It was established qualitatively that an increase in the area of paint breakdown is reflected in an increase in conductance or capacitance. The relationship between the conductance or capacitance of the system and the visually estimated area of breakdown of the paint can be examined by considering further the results shown in Figs. 6*a*, *b*, and *c* in Part II. Derived values from these data for one, two, and three coats of paint *A* are shown in Figs. 1*a* and *b*.

The curves for one and two coats in each case pass through a maximum value; the time at which this maximum occurs corresponds approximately with the time at which the values of electrode potential, and of log *R*, cease to decline rapidly (Figs. 6*a* and *b* in Part II).

The rise in these curves in the early stages suggests that the rate of increase due to extension of the area of breakdown must temporarily outweigh the rate of decrease caused by the thickening of rust on the exposed areas. The three-coat curves show, significantly, no increase.

The object of the present investigation was to study more critically the relationship between the area of metal exposed at breaks in the paint film and the measured conductance or capacitance.

Plan of the Investigation

Four series of capacitance-conductance measurements were carried out, using painted steel specimens immersed in artificial sea water. In Series I small measured areas, covering a range of sizes, were left unpainted. In Series II the breakdown of paint was allowed to proceed naturally to various stages, and the corroded area was measured. In Series III specimens that had previously been subjected to rotor tests[2] were re-immersed in stagnant artificial sea water. Series IV, carried out as a result of conclusions drawn from the results of Series I–III, comprised further measurements on re-immersed rotor specimens, with various distances between the specimens.

Series I—SPECIMENS WITH AREAS LEFT UNPAINTED

EXPERIMENTAL TECHNIQUE

Two groups of tests were carried out with (*a*) one unpainted area or holiday and (*b*) a group of holidays left on each plate. The experimental technique was the same as that used in earlier work,[1] two similarly treated plates being required for each experiment. Two coats of paint *A** (batch 3) were used, and the two coats were made to coincide very carefully at the edges of the holidays. The holidays on both plates of a pair were made as nearly as possible the same shape and size; in series (*b*) they were also similarly disposed over both plates. The plates were immersed

* See description in Part II.

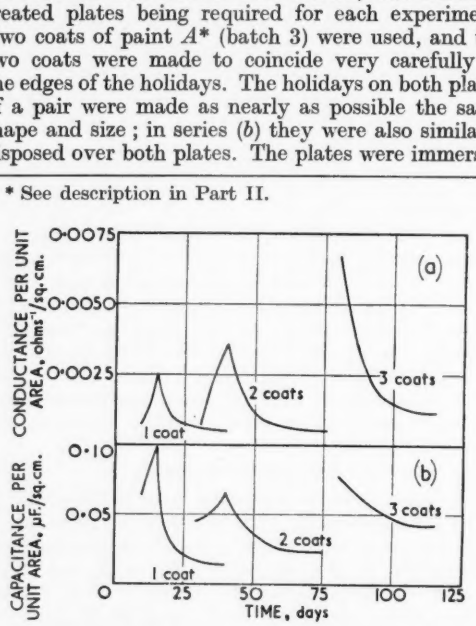

Fig. 1—Change in electrical properties for different thicknesses of anti-corrosive paint *A* (*Old series*). (*a*) Conductance; (*b*) capacitance

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with one holiday (or group of holidays) facing inwards and the other outwards ; final readings were also taken with both facing inwards. Resistance, capacitance, and electrode potential measurements were recorded in the usual manner.[1]

Before immersion of the plates the exposed areas of metal were recorded on transparent squared paper by means of an optical projection enlarger.

EXPERIMENTAL RESULTS

(*a*) Single Exposed Areas

Conductance/time and capacitance/time curves for specimens having larger unpainted areas showed, during the course of each day, a rise in value followed by a slow decrease. This was probably caused by the electrical disturbance produced in the system by taking a reading.

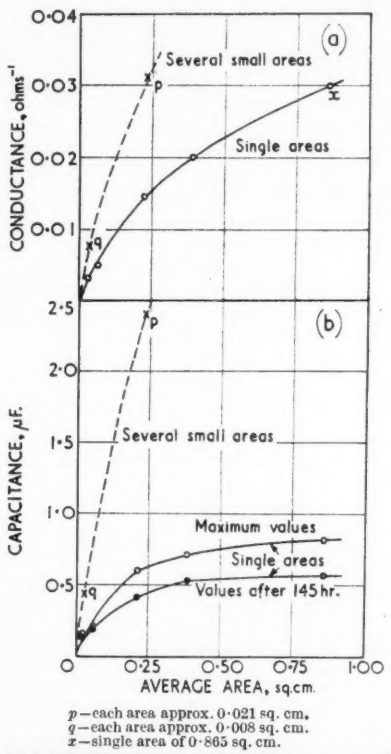
The conductance, as given by the maximum value reached each day, showed a slow decrease with time, over a period of several days, for the larger areas ; for smaller areas the value was more nearly constant. The measured conductance values after 145 hr. are given in Fig. 2*a*. The size of area plotted is the arithmetic mean of those on the two plates of a pair ; this is justifiable because the two areas were similar in magnitude.

The daily maximum values of capacitance, on the other hand, increased during the first 1–2 days and thereafter decreased steadily ; for the smaller areas ($< 0{\cdot}2$ sq. cm.) this variation was less marked. Figure 2*b* shows the maximum values reached (after 35 hr.) and the values after 145 hr.

The potential values (with respect to the saturated calomel electrode) for all these specimens remained at approximately $-0{\cdot}72$ V., that is, near the value previously obtained with unpainted specimens.

(*b*) Several Small Exposed Areas

The daily fluctuations in conductance and capacitance values were much less pronounced with several small areas than with the single larger areas. For the small areas the conductance reached a fairly steady value after a few days. The capacitance, after an initial decrease, passed through a maximum during the first 10–15 hr., becoming almost constant after 2 days. The steady values of conductance and capacitance, after 145 hr. (Figs. 2*a* and *b*), were considerably higher than those for the same area when undivided.



p—each area approx. 0·021 sq. cm.
q—each area approx. 0·008 sq. cm.
x—single area of 0·865 sq. cm.

Fig. 2—Relationship between electrical properties and area unpainted : (*a*) Conductance ; (*b*) capacitance

Series II—FULLY PAINTED SPECIMENS

EXPERIMENTAL TECHNIQUE

Experiments were carried out using one, two, and three coats of paint *A* (batch 3). Measurements of conductance, capacitance, and electrode potential were made as usual during the tests. Pairs of specimens were removed at suitable stages and the areas of breakdown were measured (after the removal of the paint and wax in hot benzene and of the rust by cathodic cleaning in ammonium citrate solution[3]).

Owing to the nature of the corroded areas it was found necessary, before measuring them on the projection enlarger, to identify the areas corresponding to paint breakdown by comparison of the cleaned corroded plates with photographs of the same plates taken before the removal of the paint. It was clear that some of the corroded areas must have coincided with small blisters (under-paint corrosion) or even undisturbed paint. One-coat systems started by rusting in many spots, blistering developing later ; in two-coat systems rusting and blistering took place together ; in three-coat systems blistering came first

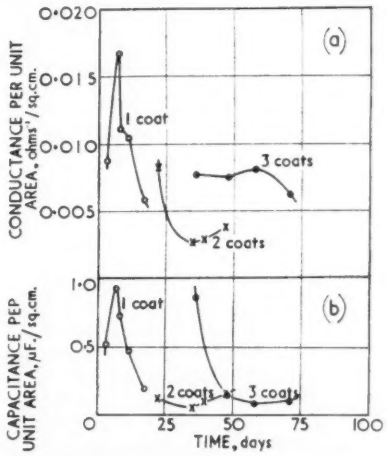


Fig. 3—Changes in electrical properties for different thicknesses of anti-corrosive paint *A* (*New series*): (*a*) Conductance; (*b*) capacitance

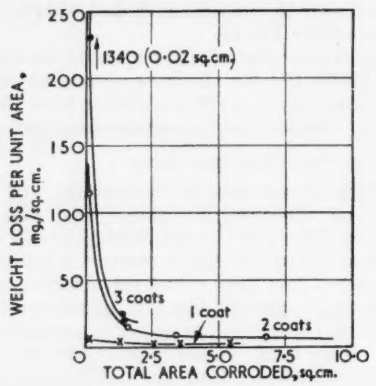


Fig. 4—Calculated average depth of penetration of corrosion for various times of immersion

and predominated throughout. Thus, in the one-coat systems in the early stages, it was assumed that all the corrosion spots corresponded with breakdown of the paint; it was not possible to make any reliable measurements on the plates in the later stages of breakdown.

EXPERIMENTAL RESULTS

The changes with time of conductance per unit area and capacitance per unit area respectively are shown in Figs. 3*a* and *b*. The conductance is the reciprocal of the measured resistance; the capacitance was measured directly. These values (for the two-plate cell) equal those for one side of one plate. The 'effective average' area A for each pair of plates is calculated from a formula similar to that for capacitances or conductances in series:

$$\frac{2}{A} = \frac{1}{a_1} + \frac{1}{a_2} \text{ or } A = \frac{2a_1a_2}{a_1 + a_2}$$

Table I

RATE OF PENETRATION OF CORROSION WITH DIFFERENT TYPES AND THICKNESSES OF PAINT

Type of Paint	Number of Coats	Total Period of Immersion, days	Time since First Appearance of Rust, days	Depth of Deepest Pits, mm.	Rate of Penetration, mm./day	Average Rate of Penetration, mm./day
A	1	8	5	<0·013	<0·0026	0·0020 (approx.)
				<0·013	<0·0026	
		17	13	0·025	0·0019	
				0·025	0·0019	
A	2	22	10	0·038	0·0038	0·0021
				0·025	0·0025	
		35	22	0·051	0·0023	
				0·038	0·0017	
		39	24	0·064	0·0027	
				0·038	0·0016	
		47	32	0·025	0·0008	
				0·038	0·0012	
A	3	36	14*	0·038	0·0027	0·0018
				0·025	0·0018	
		48	12	0·013	0·0011	
				0·013	0·0011	
		58	20	0·038	0·0019	
				0·064	0·0032	
		116	83	0·114	0·0014	
			81	0·114	0·0014	
173	2	230	140	0·280	0·0020	0·0011
		382	310	0·267	0·00085	
		301	235	0·228	0·0010	
		301	229	0·127	0·0006	
,,	2 + 1 (*AF*)	446	346	0·457	0·0013	0·0014
		446	369	0·508	0·0014	

* Some uncertainty about this figure (see text)

where a_1 and a_2 are the areas of breakdown on each plate. (The arithmetic mean is not valid here because the areas on the two plates frequently differed considerably). The magnitude of the areas of breakdown ranged, according to the time of immersion, from 0·217 to 5·37 sq. cm. for one coat, 0·128 to 6·77 sq. cm. for two coats, and 0·0128 to 1·164 sq. cm. for three coats of paint. The curves show a general similarity to those in Figs. 1*a* and *b*. They are discussed later in relation to curves obtained in Series I and III.

Relationship between Paint Thickness, Area of Breakdown, and Depth of Penetration

This section of the work arose from a consideration of the weight-loss data obtained in the experiments just described. The weight-loss per unit area of breakdown, *i.e.*, the average depth of penetration of corrosion, was calculated for each pair of specimens for various times of immersion. It would appear from the results in Fig. 4 that greatly increased depths of penetration may occur with increasing thickness of the paint coating ; *i.e.*, the more localized the attack, the greater is the rate of penetration, suggesting that the painted surface may be acting as a cathode.

Accordingly the depths of the deepest pits were measured on some of these specimens and on one pair of specimens with the same paint system *A* from earlier work. Measurements were also made on specimens painted with 173*, and on others with 173 and an additional anti-fouling coat† ; all these specimens showed highly localized attack. Most of the measurements were made with a three-dimensional toolmaker's microscope. Where the surface of a particular plate permitted, or where a check on the optical method was required, a Talysurf measurement was also taken. The results are summarized in Table I.

The rate of penetration was calculated on the basis of the time elapsing after corrosion was first seen. One value for paint *A* (three coats) is uncertain because the one corrosion spot which appeared on each plate was not observed until three days before the end of the test, but as the capacitance values showed a marked increase 14 days before the end of the experiment, this latter time was taken.

The figures in the final column of Table I show that the average rate of penetration of corrosion is of the same order for each type and thickness of paint. An increased rate of penetration did not therefore occur when only a small area of metal was attacked, as would have been expected if the whole surface of the intact paint had functioned as an efficient cathode. The shape of the curves in Fig. 4 thus reflects, not a greater rate of penetration when corrosion is confined to small areas, but rather the decrease in the average depth of penetration as the area of breakdown increases. (The time to reach a given area of breakdown increases considerably with an increase in the number of coats of paint.)

* *See* description in Part I.[3]
† Anti-fouling composition AF 10/43.[4]

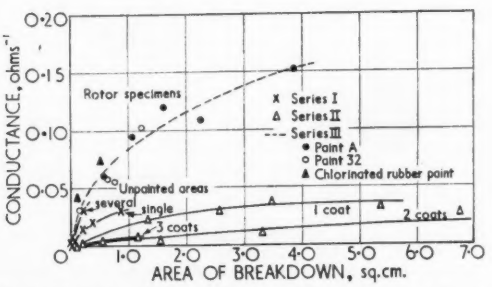


Fig. 5—Relationship between conductance and area of breakdown for Series I, II, and III

Series III — RE-IMMERSED 'ROTOR' SPECIMENS

EXPERIMENTAL TECHNIQUE

Some specimens, 2·5 cm. square, that had been used in previous rotor tests, were mounted on a steel support, heavily waxed round the back and edges, and immersed in artificial sea water. For each experiment two specimens, with approximately equal areas of breakdown, were immersed 2·5 cm. apart and with the top edges 4 cm. below the surface of the water. Average areas of breakdown ranged from 0·00116 sq. cm. to 3·87 sq. cm. Measurements of resistance and capacitance were made at intervals, until approximately steady values were obtained (generally after 24 hr.). The original rotor tests had been carried out in artificial sea water on pickled and wire-brushed specimens, coated with three different types of paint (usually three coats). Some of the specimens had been given phosphate treatments before painting.

EXPERIMENTAL RESULTS

In general, both resistance and capacitance changed appreciably during the 24 hr. after re-immersion ; the resistance almost invariably fell to a steady value ; the capacitance either fell steadily or passed through a maximum before falling. Two values of capacitance were therefore recorded, the maximum value (obtained by extrapolation to zero time in the case of a steadily decreasing value) and the final steady value. The resistance used was the final steady value.

The conductance values obtained in this series of experiments are shown in Fig. 5, together with those from Series I (*cf.* Fig. 2*a*) and II for comparison. The capacitance/area curves (not shown) are similar to the conductance/area curves.

DISCUSSION OF RESULTS—Series I–III

Effect of Rusting

The most striking feature of Fig. 5 is the very large difference between the values of the conductance for the same area of breakdown on different types of specimen. These differences are probably related to the thickness of the corrosion product on the exposed area. The product would form more easily under stagnant conditions, especially with two or three coats of paint, where the spreading of the breakdown area is relatively slow. This explanation has already been advanced to account for the shape of the curves in Figs. 1*a* and *b*. A smaller amount of adherent rust forms on the 'rotor' specimens because the movement of the specimen relative to the water tends to remove the product, and again on the partially unpainted specimens because the time of immersion is short.

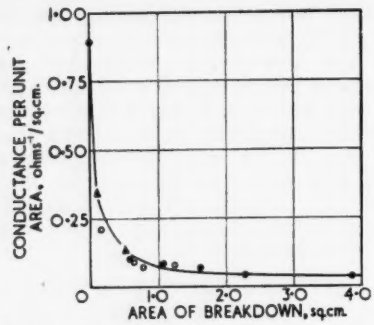


Fig. 6—Relationship between conductance per unit area and total area

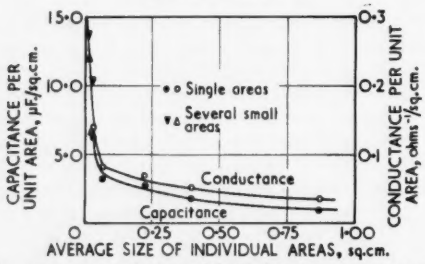


Fig. 7—Influence of size of individual unpainted areas on conductance and capacitance per unit area

Although the 'rotor' specimens represent many different types of surface pretreatment and of paint, they yield results falling closely on one curve, presumably because their surfaces are relatively free from adherent rust.

'Fringing' Effect

It is apparent that, even on one type of specimen, neither the conductance nor the capacitance is directly proportional to the total area of breakdown. The values per unit area increase both as the total area diminishes (Fig. 6) and as the size of the individual exposed areas diminishes (Fig. 7).

These results recall those of H. T. Brown,[5] who demonstrated that diffusion through a porous membrane of given total cross-section can be as rapid as diffusion through the same cross-section without the membrane. This is due to the converging of the 'lines of force' and the resultant increase in density gradient at the aperture. Similarly, in the case of conduction between two points in a large mass of conducting medium, the 'lines of flow' between the two points spread, thus increasing the effective cross-sectional conducting area.

In the system under study, while the paint film is still intact conduction can be regarded as taking place through the film itself as a whole (presumably through capillaries distributed throughout the film—*cf.* Wirth,[6] Mayne,[7] also Kittelberger and Elm[8]). At this stage the electrolyte resistance is in series with that of the film and is relatively negligible. As small points of breakdown appear on the two plates, the system becomes a high film resistance in parallel with an electrolyte resistance due to the column of sea water joining the exposed patches, neglecting the resistance at the surface of the metal due to rust, etc. As the exposed surface becomes larger, conduction through the paint can be neglected and the measured conductance can be regarded as entirely due to the sea water. Considerable spreading of the 'lines of conduction' can thus take place (Fig. 8*a*) and the effective cross-section is much greater than that of the cylindrical column joining the two exposed patches. In any calculation, therefore, of conductance per unit area, the actual exposed area on the pair of plates should be replaced by a larger, effective area.

This excess of effective over actual area constitutes the 'fringe' area (Fig. 8*b*). For a fixed distance between the two areas and a constant spreading angle α, the fringe will be of constant width f, and its area will depend on the perimeter p, of the exposed area and will approximately equal pf.

The data of Fig. 2*a* may now be reconsidered. The point x represents a single exposed area A of 0·865 sq. cm. on each plate; the conductance of a column of sea water of this cross-section, 2·5 cm. long, is 0·0172 ohms^{-1}. The measured conductance (at the conclusion of the experiment when the exposed areas were facing towards one another) was 0·0356 ohms^{-1}. The effective area A' was thus $(0{\cdot}0356/0{\cdot}0172) \times 0{\cdot}865 = 1{\cdot}80$ sq. cm. Hence f was calculated to be 0·25 cm. The areas for the other six points may be 'corrected' by adding to them the appropriate 'fringe' areas.

Table II shows the actual and effective exposed areas for the points on Fig. 2*a*, the corresponding calculated conductances, and the measured conductance. The 'corrected' values of conductance, calculated from the effective areas, are all approximately equal to the measured values, in contrast to the values calculated from the actual areas of exposed metal.

It can be concluded, therefore, that it is not generally possible to estimate the area of breakdown of the paint from conductance measurements between the two immersed plates (though an approximate method will be described later). For example, two painted plates, 2·5 cm. apart, covered with small exposed areas, each of which is surrounded by a 'fringe' 0·25 cm. wide, which touches or overlaps the fringes from the adjoining areas (Fig. 8*c*), will

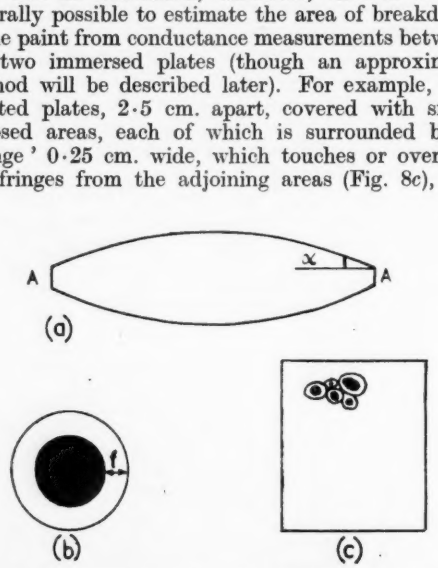


Fig. 8—Sections showing: (*a*) Conduction between two areas *AA* immersed in large conducting medium; (*b*) actual area *A* (shaded) surrounded by 'fringe' area. Large circle = *A'* = effective area; (*c*) small areas of breakdown each surrounded by 'fringe' area

Table II

COMPARISON OF CALCULATED AND MEASURED CONDUCTANCES

Actual Exposed Area, sq. cm.	No. of Individual Areas on Each Plate	Effective Exposed Area, sq. cm.	Conductance, ohms^{-1}		
			Calc. from Actual Area	Calc. from Effective Area	Measured
Single Areas					
0·024	1	0·18	0·00048	0·0036	0·0032
0·061	1	0·31	0·0012	0·0062	0·0043
0·214	1	0·67	0·0043	0·0135	0·0154
0·387	1	1·01	0·0078	0·020	0·024
0·865	1	1·80*	0·017	...	0·036
Several Small Areas					
0·032	4	0·39	0·00064	0·0078	0·0080
0·230	11	1·75	0·0046	0·035	0·032

* Calculated from conductance

give the same conductance value as two bare plates the same distance apart. (H. T. Brown[5] found that the diffusion rate—of a dye in a gel—through a column was almost unaltered if 90% of the available area was cut off by the insertion of a perforated septum). In the same way, since the variation of capacitance with the size of the individual areas is similar to that of conductance, no direct comparison of areas of breakdown is possible from capacitance measurements.

Summarizing, the series of curves shown in Fig. 5 can be accounted for on the assumption that the ' fringing ' effect is responsible for the general shape of each curve, while the relative positions of the curves are dependent on the average thickness of rust present on the exposed areas of the specimens.

Series IV—TECHNIQUE MODIFIED TO MINIMIZE ' FRINGING ' EFFECTS

A closer correspondence between the values of conductance (and capacitance) and the area of breakdown might be obtained if the effect of rusting and ' fringing ' could be reduced. The ' fringing ' effect is inherent but it might be reduced by bringing the specimens nearer together. Variations due to the thickness of the corrosion product could probably be eliminated by complete removal of the rust. This has not been tried, but further measurements were made on rotor specimens, on which the amount of corrosion product is always small, with various distances between the specimens.

EXPERIMENTAL TECHNIQUE

The procedure was as before, the rotor specimens being initially 2·5 cm. apart. Resistance and capacitance readings were taken during 24 hr., after which time a steady state was usually reached. Readings were then taken at several distances from 2·5 cm. to 0·1 cm. (It was not practicable to obtain such a series of readings corresponding to the maximum capacitance, since this value is of a too transient nature). The values for zero distance were then found by extrapolation.

EXPERIMENTAL RESULTS

The relationship between the steady resistance R and the distance d, between the specimens is shown in Fig. 9. At distances less than 0·3 cm. there is considerable diversity in the shape of the curves, those corresponding to small areas of breakdown showing an increase in R as d approaches zero. This is probably because small areas of breakdown on a pair of plates are not generally opposite ; by bringing the plates close together the distances between these exposed areas are not appreciably decreased, although the possibility of ' fringing ' is lessened. At distances apart greater than 1·0 cm. the variation of R with d is relatively small.

The variation of capacitance with distance between the plates is similar to that of conductance.

Discussion of Results

Values of conductance and capacitance found at ' zero distance apart,' plotted as ordinates against the areas of breakdown, are distributed (with considerable scatter) about an approximately straight line for areas less than 2·5 sq. cm. (conductance) and

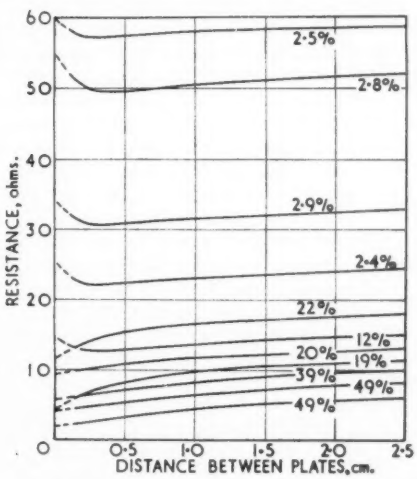


Fig. 9—Resistance between pairs of ' rotor ' specimens in sea water. Various distances apart. (Percentage figures indicate the average area of paint breakdown for each pair of specimens)

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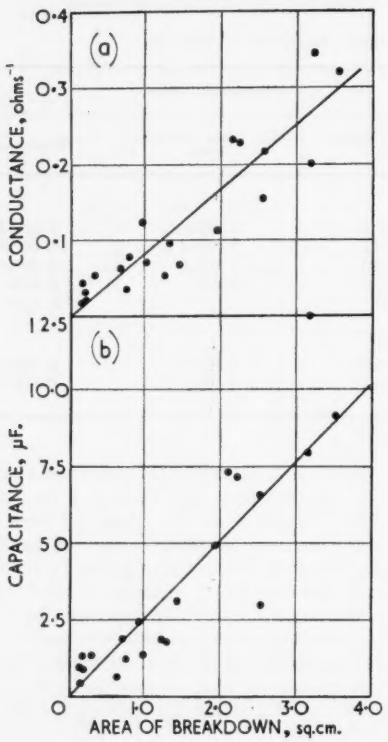

Fig. 10—Electrical properties of ' rotor ' specimens, 0·33 cm. apart. (*a*) Conductance; (*b*) capacitance

2·0 sq. cm. (capacitance) ; *i.e.*, 40% and 32% respectively of the total area. For larger areas the line curves upwards. Values measured for a gap of 2·5 cm. fall on curves similar to those in Fig. 5. The type of paint and surface preparation appear to have no effect on the measured values.

It seemed likely, therefore, that conductance and capacitance values measured at some intermediate distance apart should be capable of giving a linear relationship with areas of breakdown. For values obtained with a gap of 0·33 cm. (Figs. 10*a* and *b*) a nearly linear relationship was found to hold, with, however, a fairly large scatter (approximately $\pm 40\%$). For very small areas of breakdown, or for very large areas distributed in very small spots, the measured values of conductance and capacitance will still be unduly high, as fringing cannot be adequately compensated in these cases. It is clear that this distance apart (0·33 cm.) is dependent on the average lateral displacement of ' opposite ' exposed areas.

It may be concluded that, provided the areas of breakdown are covered with little or no corrosion product, conductance or capacitance measurements on pairs of immersed painted metal specimens, at a certain critical distance apart, can give an approximate indication of the area of breakdown.

SUMMARY AND CONCLUSIONS

The conductance of a pair of painted metal plates, immersed in an electrolyte, cannot be directly proportional to the area of breakdown of the paint, because of the spreading in the electrolyte of the ' lines of conduction ' between the exposed areas. This causes an increase in the effective cross-sectional conducting area, the smaller the individual areas of breakdown, the greater the relative effect. Capacitance values are similarly affected by the size and distribution of the areas of breakdown.

In addition, the measured conductance and capacitance are greatly influenced by the thickness of the rust deposit on the exposed areas.

An approximate estimate of the areas of breakdown of paint on a pair of metal specimens, painted on one side only and with the painted surfaces facing one another, can, nevertheless, be obtained from conductance or capacitance measurements, provided that the surface is relatively free from rust and that ' fringing ' effects are minimized by making measurements with the two surfaces a certain critical distance apart. The relative errors will be greatest for small areas of breakdown. There is no advantage in the electrical method if the areas can be measured visually, but it should prove valuable in cases where it is difficult to distinguish between areas of breakdown and the surrounding intact paint.

It has also been established, for the types and thicknesses of paint tested, that the rate of penetration of corrosion at exposed areas in the paint film is independent of the relative areas of the exposed metal and of the intact paint film ; hence it appears that the whole surface of the paint film is not functioning as an efficient cathode.

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Macroscopic Surface Stresses Produced by Plastic Deformation

By G. B. Greenough, Ph.D.

SYNOPSIS

It is not possible to explain the residual lattice strains observed in plastically extended polycrystalline aggregates, using X-ray diffraction methods, entirely in terms of Heyn intergranular stresses. This paper is concerned with the possibility that macroscopic (large-scale) stresses are also present, superposed on the Heyn stresses, in iron and mild-steel specimens. It is shown that there is a macroscopic compressive biaxial stress in the surface of the aggregate; the layer containing this stress is, in the specimens used, about two crystals (8×10^{-3} in.) deep. The whole of the transverse component of this stress system is confined to the surface layer and is determined; the longitudinal component may not be entirely confined to the surface layer, and only the difference between its value at the surface and in the interior is measured.

When a polycrystalline metal specimen is subjected to stress, the average spacing between the various lattice planes in each crystal of the aggregate changes. For any particular family of planes, the change in the position of the intensity maximum of the appropriate X-ray diffraction line can be used to measure the change in the average spacing of the planes in all those crystals contributing to the diffraction line. Small variations of the interplanar spacing from point to point in the crystals cause a broadening of the diffraction line and, although studies of this phenomenon are of great importance, the present work has been confined to a study of the average strains in the crystals, termed lattice strains.

Earlier work[1, 2] has shown that if a polycrystalline aggregate is plastically deformed, lattice strains remain in the specimen when the deforming stress has been removed. One of the causes of these residual lattice strains is the Heyn intergranular stress system arising from the variation of the yield tension with orientation of the grains in the aggregate, coupled with the fact that only grains with a limited range of orientations contribute to a particular X-ray diffraction line. However, such an intergranular stress system does not entirely account for the observed residual lattice strains, and it has been suggested that there is, in addition, a macroscopic compressive stress in the surface layers of the specimen.

Grains that lie in the surface of a polycrystalline specimen differ from those completely surrounded by other grains in that, when the aggregate is plastically deformed, the grain is not compelled to maintain contact with neighbouring grains at all surfaces. With the free surface the surface grain can, to some extent, behave more like a single crystal and can deform in the easiest manner. The amount of slip on the less favourably orientated glide planes is probably less in a grain of given orientation in the surface than in one of the same orientation deep in the aggregate; hence the yield tension of the former would be less. After the release of the applied tensile stress, these soft parts would be driven into compression by the hard parts, and a macroscopic compressive stress, *i.e.*, a stress having the same value for grains of all orientations, would appear in the surface of the specimen, balanced by a macroscopic tensile stress in the interior. These stresses would be superposed on the Heyn intergranular stresses.

The major component of the macroscopic stress would be expected to be parallel to the direction of plastic extension of the specimen. However, the experimental work was carried out assuming the presence of a biaxial macroscopic stress system in the specimen surface; there can be no stress in the region examined in a direction perpendicular to the surface, because the X-rays only penetrate the metal to a small depth.

A low-carbon steel, which is known to give large residual lattice strains, was examined, so that experimental errors in the strain determination would be relatively small. This material shows residual lattice strains which are three or four times as large as those in face-centred cubic metals and has the advantage that small-grained specimens can easily be prepared, making it unnecessary to scan large areas of specimen to obtain an X-ray diffraction photograph representative of the average behaviour of those grains with the correct orientation to contribute to the diffraction line. On the other hand, it is not possible to make a valid theoretical estimate of the magnitude of the Heyn stresses left in mild steel by plastic deformation, as is possible for a face-centred cubic metal.[1] This is a disadvantage when attempts are made to interpret the measured strains in terms of stresses, but it was considered to be outweighed by the advantage of the higher experimental accuracy.

Although the magnitude of the residual lattice strain increases with increasing plastic deformation, so also does the diffraction line broadening. Thus, the experimental accuracy of the strain determinations decreases as the strains become larger. From past experience it was decided to compromise between a high accuracy of measurement and large values of the residual lattice strains by employing plastic strains of 5–10%, obtained in the annealed iron and steel by applying stresses of about $4{\cdot}0$–$4{\cdot}5 \times 10^4$ lb./sq. in.

Since the individual crystals in the aggregate are

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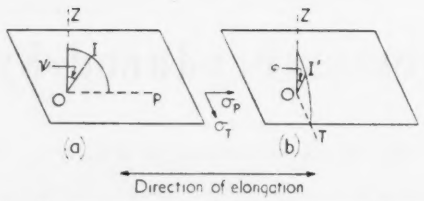

Fig. 1—Strains in a plastically deformed specimen showing (*a*) that strains due to both σ_P and to intergranular stresses vary with ψ, and (*b*) that strains due to σ_T vary only with ϕ

elastically anisotropic, the values of the elastic constants relating the lattice strains, measured using a particular diffraction line, to the stress in the aggregate are not necessarily the same as the bulk macroscopic constants, nor are they the same as those for other diffraction lines. Unfortunately, some of the appropriate values for this work have not been determined experimentally, and their theoretical calculation is not free from assumption. Although any allowance made for this variation in elastic constants affects the correlation of strains measured using different diffraction lines (*see* p. 240), the normal macroscopic elastic constants have been used throughout this paper. Young's modulus E has been taken as 29×10^6 lb./sq. in., and Poisson's ratio ν as 0·28.

MEASUREMENT OF THE TRANSVERSE MACROSCOPIC STRESS

Method

In the absence of Heyn intergranular stresses, *i.e.*, when the stress is the same in grains of all orientations, it is possible to measure two principal macroscopic stresses when their directions are known. For example, the two stresses σ_P and σ_T in Fig. 1 could be determined from the lattice strains measured (separately) in the directions *OZ*, *OI*, and *OI'*. But this method assumes that the only reason for the difference in the strain in directions *OZ* and *OI* is the different inclination of the direction of measurement to the common stress; this is not true for a plastically extended specimen, where Heyn intergranular stresses exist.

In a plastically deformed specimen, grains whose orientations in the direction of plastic elongation are dissimilar are left in different states of stress. Thus, if the lattice strains are determined when the normals to the reflecting planes lie in various directions in the plane *ZOP* (Fig. 1*a*), the contribution of the intergranular stress to the observed lattice strain varies with ψ, and it is not possible to deduce the macroscopic stress component σ_P from the measured strains. On the other hand, if the strains are measured in various directions in the plane *ZOT* (Fig. 1*b*), all the reflecting normals make the same angle with the direction of elongation, and all the intergranular stress components in the reflecting grains should be the same. It should be possible to deduce the macroscopic stress σ_T from these measurements, although an experimental check that there is little variation in the transverse stress from grain to grain would be desirable.

The relation between the strain in any direction *OI'* in the plane containing the principal stress σ_T and the normal to the surface is given by:

$$\epsilon_\phi = \frac{\sigma_T}{E}(\sin^2\phi - \nu\cos^2\phi) + K \quad \ldots\ldots\ldots\ldots (1)$$

where K is the strain resulting from the stress perpendicular to σ_T. In this case, both the macroscopic stress σ_P and the Heyn microscopic stresses contribute to K, which, as pointed out above, is probably independent of ϕ. If this assumption is correct, the values of ϵ_ϕ, determined for several values of ϕ, can be related to a single value of σ_T by equation (1). In this work the strains were measured for four values of ϕ, so that the assumption that K was independent of ϕ could be checked.

To determine macroscopic stresses in the surface of a plastically extended iron specimen, Wood and Dewsnap[3] carried out strain measurements in two directions in the plane *ZOP*, and used the equation analogous to (1), with ψ in place of ϕ and K' in place of K, to deduce the macroscopic stress σ_P. If only two values of ψ are used, a numerical result can always be calculated for σ_P, provided that K' is assumed to be constant. In general, K' is not constant; hence values of σ_P deduced by this method are never reliable.

Experimental Details

The work was carried out using a low-carbon steel containing 0·10% C, 0·36% Mn, 0·017% Si, and 0·007% P. Flat test pieces, with a gauge length of cross-sectional area $\frac{1}{4} \times \frac{1}{8}$ in., were accurately machined and all faces were polished. The test pieces were annealed in a good vacuum at 950° C. for $\frac{1}{2}$ hr. and were slowly cooled in the furnace. A stationary back-reflection Laue photograph showed sharp Laue spots, indicating that the crystals were strain-free. Micrographic examination of sections through typical specimens showed no evidence of decarburization at the surfaces; the average diameter of the grains was about 1×10^{-3} in.

A flat-plate back-reflection camera was used to record the X-ray diffraction lines, the film–specimen distance being determined using a calibrating silver powder on the surface of the specimen. The lattice spacing of any particular diffraction line from a specimen was determined without using the extrapolation techniques often employed in powder camera work, since camera and film shrinkage errors were sufficiently eliminated by suitable use of the calibrating diffraction lines. In the particular camera employed, the diameter of the incident X-ray beam was about $1\frac{1}{2}$ mm., and the film–specimen distance was about 10 cm. The specimens were oscillated through $\pm 2\frac{1}{2}°$ during the exposures. To record the 310, 211, and the second order of the 110 diffraction lines, CoKα, CrKα, and MnKα radiations were used.

The specimen was placed so that the incident X-rays and reflecting plane normals were in the plane *ZOT* (*see* Fig. 1*b*). Observations were first made only on the 310 diffraction line, when the incident beam made angles $\Phi = 0°$, 30°, 45°, and 60° with the normal to the specimen surface. Since the diameters of the diffraction rings are employed to determine the Bragg angle of diffraction θ, the interplanar spacing d, determined from the Bragg equation $2d \sin\theta = \lambda$, is the mean of the values for the two families of grains diffracting to each side of the ring. The angle between

the normal to the specimen surface and that to the reflecting planes is either $\phi_1 = \Phi - (90° - \theta)$, or $\phi_2 = \Phi + 90° - \theta$.

Two specimens were used in this experiment, and X-ray photographs were taken from each of the two broad faces, at all angles of incidence of the beam. For the two larger values of Φ, two photographs were taken from each side, but at the lower values only one was taken. The interplanar spacing in the annealed specimens was determined from photographs taken at all four angles of incidence ; these agreed with each other within the limits of experimental error.

The loading was carried out using a standard form of tensile-testing machine, which incorporated shackles designed to apply an axial load to the specimen. A tensile stress of $4{\cdot}30 \times 10^4$ lb./sq. in. (measured on the final area of cross-section) was applied, which caused a plastic extension of about 6%. The interplanar spacings in the strained aggregate were then measured, and the residual lattice strains were determined.

Results

For a given angle of incidence of the X-ray beam, the residual lattice strains on each side of both specimens were the same within the limits of experimental error, and the results from the two specimens agreed with each other. Mean values of all the residual lattice strains determined at each value of Φ were therefore taken and are shown in Table I. The probable error in these mean values is $\pm 1 \times 10^{-5}$.

Since the measured strains are the mean values of the strains in the directions $\phi_1 = \Phi - 90° + \theta$ and $\phi_2 = \Phi + 90° - \theta$, equation (1) must be slightly modified to relate the measured strains ε_Φ to the stress and to Φ. The modified equation is

$$\epsilon_\Phi = \frac{\sigma_T}{2E}[1 - \nu + (1 + \nu)\cos 2\Phi \cos 2\theta] + K \ldots \quad (2)$$

The value of σ_T most nearly satisfying all four values of the observed strains ε_Φ is $6{\cdot}1 \times 10^3$ lb./sq. in. (compressive). Table I shows the calculated contributions due to the macroscopic stress σ_T, for each angle of incidence, and the difference K between this and the observed value. This difference should be constant and equal to the sum of the strain contributions from σ_P and the Heyn stresses. The results indicate that the difference is constant within the limits of experimental error, and hence it is clear that there is little variation of the transverse stress component from grain to grain.

Table I

RESIDUAL LATTICE STRAINS IN VARIOUS DIRECTIONS PERPENDICULAR TO THE DIRECTION OF ELONGATION

	Angle between X-ray Beam and Surface Normal, Φ			
	0°	30°	45°	60°
Observed residual lattice strain, $\epsilon_\Phi \times 10^5$	29	25	16	12
Calculated strains due to experimentally determined $\sigma_T \times 10^6$	5	−1	−8	−14
Strain due to σ_P and Heyn stresses, $K \times 10^5$	24	26	24	26

Table II

RESIDUAL LATTICE STRAINS NORMAL TO SPECIMEN SURFACE

Specimen	True Stress Previously Applied, lb./sq. in. $\times 10^4$	Plastic Extension, %	Residual Lattice Strain $\times 10^5$		
			310	211	110
Large flat test piece	4·30	6	29	13	3
Wire	4·2	10	22	9	−2

The two specimens were also examined with incident X-ray beams normal to the specimen surface, to determine the residual lattice strains shown by the 211 and 110 reflections. The results, shown in Table II, are compared with those previously determined[2] for the same mild steel in wire form.

Discussion of Results

From this experiment it may be concluded that if a specimen of mild steel is extended by a uniaxial tensile stress of $4{\cdot}30 \times 10^4$ lb./sq. in. and the stress is then removed, a transverse compressive stress of $6{\cdot}3 \times 10^3$ lb./sq. in. appears in the surface (but is not necessarily confined to the surface).

If the residual lattice strains are measured in plastically extended wires, using a Bradley-Jay type of powder camera in which the wires are completely bathed in X-radiation, the strain observed will not be the same as that observed using a large flat specimen with the X-ray beam incident normal to the surface. In the latter instance, all the reflecting normals are perpendicular to the Heyn stress, to σ_P, and to σ_T, but with the wire specimen the reflecting normals, although perpendicular to the Heyn stress and to σ_P, make various angles with the transverse stress component σ_T (*see* Fig. 2). If the intensity of the X-rays contributed, by unit area of the wire, to a back-reflection line on which the X-rays are incident at an angle $90° - \alpha$, is assumed to be proportional to $\cos\alpha$, then the net contribution of the whole wire to the total residual lattice strain by the transverse

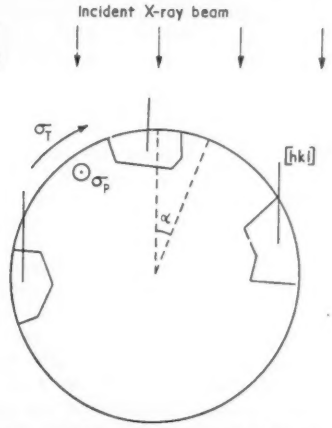

Fig. 2—Section of plastically extended wire, showing variation of angle between σ_T and normals to *hkl* diffraction planes over irradiated area

stress σ_T is $2\sigma_T(1 - 2\nu)/3\pi E$, which corresponds to equation (1) rather than to the modified equation (2).

For $\sigma_T = 6{\cdot}1 \times 10^3$ lb./sq. in., the calculated difference beween the residual lattice strains shown by a particular diffraction line from a wire specimen and from a large flat specimen is 6×10^{-5}. This figure agrees with the differences between the results for the two types of specimen, shown by each of the three diffraction lines quoted in Table II ; this affords strong confirmation of the value determined for σ_T.

The difference between the residual lattice strains shown by the various diffraction lines in both types of specimen confirms that Heyn stresses exist in plastically deformed fine-grained polycrystalline aggregates. The magnitude of the differences gives some indication of their size ; they are by no means negligible.

The value of the transverse stress determined by Wood and Dewsnap, after the plastic extension (9·4%) of a similar mild steel, was $6{\cdot}7 \times 10^3$ lb./sq. in. (compressive).

DEPTH OF STRESSED LAYER

The possibility that macroscopic stresses in the surface layers of plastically extended specimens, balanced by opposite stresses in the interior, were responsible for the observed residual lattice strains, has been examined several times, using two types of experiment. In the first type, X-ray diffraction methods have been used to measure the total lattice strain in a direction normal to the surface, and this strain has been determined at surfaces successively exposed by etching away parts of the metal. In the second, mechanical methods of measuring strain have been used, and possible changes in strain have been investigated during etching.

Bollenrath, Hauk, and Osswald[4] employed the X-ray method, and showed that the residual lattice strain in a plastically extended mild-steel bar decreased as the specimen became thinner. Their results indicated that there was a compressive macroscopic biaxial stress confined to a layer at the original surface of the specimen. Smith and Wood[5] performed an analogous experiment, and showed that the observed residual lattice strain remained approximately constant at surfaces exposed by etching specimens. Greenough[6] reported similar experiments carried out on wires, which also showed an approximately constant strain in the surface exposed by etching.

Davidenkov and Timofeeva[7] made mechanical strain measurements on plastically extended aluminium sheets as the surface layers were etched away ; Moeller and Neerfeld[8] performed a similar experiment on plastically extended mild-steel bars. Both concluded that there was no appreciable surface layer containing macroscopic stresses differing from those in the interior.

Bollenrath *et al* found that the stress sum in the surface was approximately equal to the stress causing the plastic deformation of the specimen, *i.e.*, 40×10^3 lb./sq. in. and that the depth of the stressed layer was about 1 mm. : other workers [5, 6, 8] would certainly have detected a stress system of this magnitude. It is therefore probable that, if there is a macroscopically stressed layer in the surface of the aggregate, either the magnitude of the stresses, or the depth of the stressed layer, is much less than that found by Bollenrath.

Glocker and Hasenmaier[9] examined plastically deformed mild-steel specimens while the deforming load was being applied and showed that the stresses determined using CoKα and CrKα radiations were different. They attributed this to the different penetrative power of the radiations, and concluded that the surface layer had a lower yield stress than the interior. Their conclusion, however, is not reliable, since they give no reason why the possible alternative explanations of microscopic Heyn stresses or variations of elastic constants, were rejected.

In connection with any experiment involving the etching of steels, it is important to note that Lihl[10] has shown that etching annealed, strain-free specimens of many types of mild steel will introduce compressive biaxial stresses into the surface layers ; he ascribes this to the absorption of hydrogen by impurities in the steel. Therefore, before any experiment employing etching techniques is made on mild steel, a check must be made to ensure that the steel is not affected by the etching treatment itself. The steel used in the experiments described on p. 236 developed compressive stresses during the electrolytic etching process used, and consequently could not be used in this second part of the research.

Experimental Methods

The principle of the experiment was identical with that used by Bollenrath *et al*. The residual lattice strain was measured when the incident X-ray beam was normal to the surface of the plastically extended specimen. A small depth of metal was then removed and the residual lattice strain was again determined, the process being repeated many times. If the surface layer contained macroscopic stresses differing from those in the interior, the strain should at first change, and should then assume a constant value. Etching is the only method by which it is possible to remove metal without introducing further stresses—mechanical methods are known to produce high stresses in the resulting surface.

After testing various types of iron and steel, it was decided that Armco iron was satisfactory, since etching this material in the annealed condition produced no change in the lattice spacing, within the limits of the experimental error. The analysis of the Armco iron was : 0·019% C, 0·035% Mn, 0·040% S, 0·008% P. The faces of carefully prepared flat test pieces, with a gauge length of cross-sectional area $\frac{1}{4}$ in. $\times \frac{1}{8}$ in., were polished. To obtain a specimen in which the grains were strain free and reasonably small, the material was annealed at 850° C. for 3 hr., then at 880° C. for 1 hr., and then slowly cooled in the furnace. The grain size varied, the average diameter being about 3×10^{-3} in. This is rather large, but since strain measurements from various test pieces were not significantly different, it was concluded that it was small enough to ensure that the strains measured were a true average of those in the grains of the appropriate orientations.

The purpose of the experiment was to detect

changes in the observed lattice strain, arising from the removal of possible macroscopically stressed layers, and it was desired that contributions from the Heyn intergranular stresses should remain unaffected throughout. It was thus essential that the etching should neither leave an uneven surface nor give any preferential attack at the grain boundaries, since the occurrence of either of these would lead to a relief of microscopic Heyn stress in the parts of the specimen contributing to the X-ray diffracted beam. An electrolytic method of removing metal was employed, using the type of bath developed for electrolytic polishing.[11] The specimen was made the anode in a bath containing 63 c.c. of 60% perchloric acid, 800 c.c. of industrial methylated spirit containing 3% of ether, and 146 c.c. of water. The potential difference required to give satisfactory surfaces was about 35 V. when the anode-to-cathode distance was about $3\frac{1}{2}$ in.; this removed iron at a rate of about 7×10^{-4} in./min. from the face opposite the cathode. To ensure that only the face under examination should be etched, the remainder of the specimen was protected by rubber solution before treatment. Examination, both of the surface and of sections cut normal to the prepared surface, showed that the surfaces left after etching were smooth.

Observations were again made on the 310, 211, and on the second order of the 110 reflections, at all stages of the experiments using the X-ray apparatus already described (*see* p. 236). The arrangement of the specimens was such that the X-ray beam was incident along *OZ*, the normals to the reflecting planes being in the plane *ZOT* (Fig. 1*b*). Two photographs were taken with each of the appropriate X-radiations, the broader faces of both specimens being examined at all stages of the experiment.

After the appropriate strain-free lattice specimens had been obtained, each specimen used was loaded, using axial loading shackles, to a true stress of $4{\cdot}41 \times 10^4$ lb./sq. in., which gave a plastic extension of about 11%. The interplanar spacings of the strained metal were then measured and the residual lattice strains were determined. One face of each specimen was then etched to a small depth, about 2×10^{-3} in., and the residual lattice strains were again determined. This process was repeated many times, etching each of the broader faces alternately. The thickness of the layer etched away from each face was determined from the thickness of the specimen before and after etching, as measured by a micrometer. The strains determined are those which exist after the surface layers have been removed; the results show that the stressed layer on the specimen is so thin compared with the thickness of the specimen that no appreciable bending of the specimen occurs when the layer is removed from one side only.

Results

Four specimens were examined, but the plastic extension of the first pair of specimens was rather less than that of the second pair. The figures quoted for stresses and for residual lattice strains are those obtained for the second pair of specimens; the results for the first pair agree with these figures if allowance

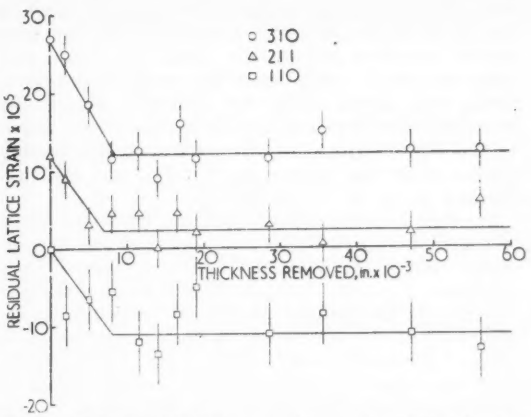

Fig. 3—Relationship between observed residual lattice strains in Armco iron, and the depth below surface

is made for the difference in the initial deforming stress. In every case the residual lattice strains observed on opposite sides of a given specimen were the same within the limits of experimental error; so also were the results from the two specimens.

In Fig. 3 the residual lattice strains observed for each of the three diffraction lines are plotted against the total depth of surface removed before the observation was made; no distinction is made between points from different surfaces or from different specimens. Each point represents the mean strain determined from both the α_1 and α_2 diffraction lines on two photographs. A line is drawn through each point to represent its average probable error; these errors are $\pm 2{\cdot}_5$, $\pm 2{\cdot}_5$, and ± 4 ($\times 10^{-5}$) for the 310, 211, and 110 reflections respectively, although the value for the original surface is more accurate. For each family of reflecting planes the points were approximately on the lines drawn in Fig. 3. In every case the residual lattice strain decreases rapidly as the surface is etched away, until about 8×10^{-3} in., which corresponds to two or three grains, has been removed; it then becomes approximately constant.

During the etching experiments a few photographs were taken with the X-ray beam incident in the plane *ZOT*, and making an angle of 45° with the specimen surface. Using the 310 reflection only, observations were made to determine σ_T after removing various depths of metal from the surface of the specimen. The results showed that the macroscopic stress σ_T decreased from $5{\cdot}7 \times 10^3$ lb./sq. in. (compressive) at the surface to approximately zero at a depth of 8×10^{-3} in.

Discussion of Results

Since the results from opposite sides of any particular specimen agree with each other, none of the results obtained can be due to plastic bending of the specimens caused by non-axial loading.

One of the basic assumptions made in this part of the work was that etching away metal from the surface of the specimen would affect only the macroscopic stress systems in the specimen. In particular, it was assumed that the Heyn microscopic stresses were the same everywhere in the specimen, and that

the etching treatment would expose surfaces in which the lattice strains shown by the three diffraction lines would remain relatively the same, *i.e.*, that each diffraction line would show the same variation of strain with depth below the surface. It appears, however, that the reduction in lattice strain shown by the 310 line (15×10^{-5}) may be just significantly greater than that shown by the 211 and 110 lines (10 and 11, $\times 10^{-5}$ respectively).

It must be remembered that the measured strain is not that in an infinitely thin skin at the exposed surface but is the average strain in a layer of finite thickness, since the incident X-ray beam penetrates the metal; the precise penetration depends on the wavelength. It can be shown that more than 50% of the diffracted intensity comes from layers of thickness less than $1{\cdot}1 \times 10^{-3}$ in. for the 310 reflection, less than $0{\cdot}4 \times 10^{-3}$ in. for the 211 reflection, and less than $0{\cdot}8 \times 10^{-3}$ in. for the 220 reflection. However, since the most penetrating radiation shows the largest change of strain, this consideration cannot explain the discrepancy.

The most likely explanation lies in the elastic anisotropy of the grains in the aggregate. Allowance can be made for the variation of ν/E for the different diffraction lines, *e.g.*, by using the values experimentally determined by Neerfeld,[12] who showed that the macroscopic value was $0{\cdot}95 \times 10^{-6}$/lb./sq. in., and the values appropriate to the 310 and 211 diffraction lines were $1{\cdot}19$ and $0{\cdot}86 \times 10^{-6}$/lb./sq. in. respectively. The stresses corresponding to the measured strains are then $12{\cdot}6$ and $11{\cdot}6 \times 10^3$ lb./sq. in. for the 310 and 211 diffraction lines respectively. These are identical within the limits of error of the experimental work described here. Unfortunately, no accurate values for ν/E for the 110 diffraction line are available and a complete correlation of the stresses represented by the reductions in strains is not possible. The graphs in Fig. 3 can thus be interpreted as showing that a macroscopic biaxial stress sum of 12×10^3 lb./sq. in. (compressive) exists in a surface layer approx. 8×10^{-3} in. deep.

The conclusion (*see* p. 237) that it is possible to measure the transverse macroscopic stress σ_T by observations in different directions in the plane containing σ_T, is probably true for Armco iron as well as for the low-carbon steel. Thus the value $\sigma_T = 5{\cdot}7 \times 10^3$ lb./sq. in. at the surface represents a true macroscopic stress. Experiment has shown that σ_T is entirely confined to the surface layer; therefore, the difference between the biaxial stress sum in the surface layer and σ_T must be due to σ_P. Thus, the part of the macroscopic longitudinal stress σ_P that is confined to the surface layer is $6{\cdot}3 \times 10^3$ lb./sq. in. (compressive). There is no experimental evidence to indicate whether this is the whole or part of σ_P.

The total change in lattice strain observed when the surface layer is removed from a large specimen is $-\nu(\sigma_P + \sigma_T)/E$, but for a wire it is $\left[\frac{2\sigma_T}{3\pi}(1 - 2\nu) - \nu\sigma_P\right]/E$, *i.e.*, the change is much smaller. Earlier work[6] on wires was designed to investigate whether the whole of the residual lattice strain shown by the 310 planes resulted from a macroscopically stressed surface layer, and it was not sufficiently accurate to measure the small change that should have occurred. The results of the present work agree neither with those of Bollenrath *et al.*,[4] who found a much greater stress in the surface layer (which was much thicker), nor with those of Smith and Wood,[5] who found no macroscopically stressed surface layer. It is difficult to advance any reasons for these discrepancies, unless it is that the earlier workers were not employing a suitable combination of steel and etching technique.

It is, however, apparent that the work of Davidenkov and Timofeeva,[7] and that of Mœller and Neerfeld[8] failed because they were using comparatively thick specimens (about 1 in. thick in the case of the latter authors), and thus the tensile stresses required in the interior to balance the compressive stress in the thin surface layer would be very small. The relief of this stress by the removal of the surface layer would produce a change in external dimensions of the body too small to be differentiated from experimental error. However, these authors should have detected the presence of a macroscopically stressed layer of the type found by Bollenrath.

CORRELATION OF EXPERIMENTAL RESULTS

Although in the course of the experiments it was found that the low-carbon steel, used in the earlier wire experiments[2] and in the tests described on p. 236, was unsuitable for the etching experiments, the conclusion that there is little variation in the transverse stress from grain to grain is likely to be of general validity, rather than only applicable to mild steel. Consequently, it was decided not to repeat the whole of the detailed work, including the work on the wires, using the Armco iron, but merely to redetermine the value of the transverse stress on the surface of the plastically extended specimen.

The main difference between the two materials is that under the metallurgical microscope the low-carbon steel shows small amounts of cementite, whereas Armco iron appears to be entirely ferritic. This probably accounts for the difference in the plastic strains produced by approximately the same applied tensile stress. The residual lattice strains observed in the initial surface of the Armco iron (Fig. 3) do not differ significantly from those shown by the larger mild-steel specimens (*see* Table II). The values of the transverse macroscopic stress in the surface of each specimen are also the same, indicating that the internal stresses developed after plastic extension are little influenced by minor differences in the microstructure, and are likely to be more dependent on the stress causing plastic flow than on the amount of the deformation. The latter conclusion is in accord with the simple theory advanced previously.[2]

If the values of the Heyn stresses could be estimated from a knowledge of the applied stress and the mechanics of the deformation of the crystals in the aggregate, it would be possible to ascertain whether the value of $6{\cdot}3 \times 10^3$ lb./sq. in. (compressive) represented the whole, or a part of, the longitudinal compressive stress σ_P in the surface of the specimen. This assessment can only be made in the case of face-centred cubic metals, where the residual lattice strains are too small to be measured sufficiently

accurately, with present experimental techniques, to make the analysis feasible. If it were shown that the total value of σ_P differed from the part determined, some form of stress system, not discussed here, would have to be postulated to account for the residual part of σ_P, which would be a longitudinal stress acting throughout the specimen.

From their experimental work Wood and Dewsnap[3] deduced the total magnitudes of σ_P and of σ_T at the surface, but made no attempt to determine the variation of these quantities with depth below the surface. After a 9·4% plastic extension of a mild steel, the values of σ_P and σ_T at the surface were 10 and 6·7, $\times 10^3$ lb./sq. in. respectively, both compressive.

CONCLUSIONS

(1) In plastically extended polycrystalline iron and mild-steel specimens, in addition to a system of Heyn intergranular stresses, which extends right through the specimen, there is a macroscopic stress system in the surface grains. This stress system is biaxial, both components being compressive. In the Armco iron specimens the stressed layer was about 8×10^{-3} in. thick, which corresponds to two or three crystal diameters (the latter is probably the more important measure of thickness).

(2) After plastic deformation produced by an applied tensile stress of $4{\cdot}3 \times 10^4$ lb./sq. in., the component of the macroscopic stress in a direction perpendicular to the direction of elongation is 6×10^3 lb./sq. in. (compressive); this component is confined entirely to the surface layer. It was not possible to measure the total macroscopic stress component in a direction parallel to that in which the specimen was elongated, but the part of it which is confined to the surface layer has a value of 6×10^3 lb./sq. in. (compressive). These figures agree well with those found in the surface by Wood and Dewsnap.[3]

(3) The development of a compressive stress in the surface layer in a direction parallel to that of elongation of the specimen is readily explicable, because the yield tension of grains with a free surface is lower than that of grains with the same orientation completely surrounded by other grains. It is not easy to explain the development of the transverse compressive stress in the surface layer.

Acknowledgments

The author thanks Mr. E. Parry and Mr. B. I. Tait for carrying out much of the laborious work associated with the exposing and measuring of the many X-ray films used in this work.

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HISTORICAL NOTE NO. 25

A Tudor Furnace in Waterdown Forest

By Dr. H. R. Schubert

THE main road from Tunbridge Wells to Mayfield in Sussex affords a most beautiful view into a well-wooded area now mainly covered by Eridge Park. These woods are remnants of the ancient Forest of Waterdown, which constituted the eastern part of the belt of woodland that extended right across the northern part of the county.

By indenture of 25th June, 1562, Henry Nevill, Lord Abergavenny, possessed of the Manor of Rotherfield and the Forest of Waterdown, and Edward Nevill granted to Bartholomew Jeffrey and William Relfe "*power and liberty to erect and build . . . one furnace for the blowinge, castinge and makinge of iron sowes or any other roughe or cast iron*." at a convenient place within the Forest or Chase of Waterdown but so that Lord Abergavenny's corn mill known as Redgate mill (situated north of Rotherfield and still existing), should not be incommodated, and also granted to them power to make the necessary arrangements for leading water to the furnace and storing it in ponds. They were also granted sufficient supply of wood for charcoal burning and of iron ore, and permitted to build cottages for ironworkers and colliers. The grant should be valid for ten years, but every year Lord Abergavenny should be able to use

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the furnace with his own workmen for five foundays (*i.e.*, a founday contained six days).[1]

The furnace was erected at Cowford 1½ miles north of Rotherfield in Sussex. This happened immediately after the date of the indenture, for in the following year of 1563 the two ironmasters, Relfe and Jeffrey who jointly worked it, delivered 61 tons of sow iron to Robertsbridge forge in Sussex.[2] The same quantity of sow iron was sent there in each of the years of 1565 and 1566.[3]

The Cowford furnace was one of the many furnaces in the Weald where ironworkers of French origin were still employed more than half a century after the introduction of the blast-furnace from France to England. The founder Gillham (*i.e.*, Guilleaume) Bygnole or Bignall was a Frenchman. Another of the furnace workers who is not named was French also ; probably he was the filler who was responsible for the charge.

The indenture of 1562 dates the existence of Cowford furnace back by 41 years from the earliest evidence known.[4] It also shows that Lord Abergavenny's furnace, which was in Eridge between Rotherfield and Tunbridge Wells and which is first referred to in a list of furnaces compiled in 1574,[5] was already in existence in 1562. Otherwise, the clause that the Lord should be enabled to make use of Cowford furnace for 30 days within a year, should he so desire, would make no sense. He would not keep "*his own Workmen*" just for the pleasure of using another man's furnace for about four weeks within the year.

The clause that trees already sold to Nicholas and Anthony Fowle should be excepted from cutting for the use of Cowford furnace, indicates the existence of two more furnaces in the vicinity in 1562, *i.e.*, 12 years earlier than the first evidence known up to now. They were Maynard's Gate west of Rotherfield, and Riverhall, northeast of Rotherfield, the former being worked by Anthony Fowle before 1574, the latter by Nicholas who is thought to have been his brother.[6] Thus the indenture of 1562 contains evidence of four furnaces in Ashdown Forest and the adjacent area, all erected in or before 1562.

The supply of iron ore for the furnace of Cowford presented no difficulty, as its site was in the immediate vicinity of an area where ore was mined as early as in the first century B.C. by Celtic prospectors for iron. They dug the ore in the hills adjacent to Saxonbury Camp, a Celtic hill-top fort erected before Caesar came to Britain. The camp was a fortified settlement which gave protection to the iron miners and smelters against hostile tribes, wolves, and outlaws hiding in the inaccessible woodlands of this area.[7]

There was also an ample supply of wood for charcoal burning. The indenture of 1562 guaranteed the ironmasters 12,000 cords of wood from Waterdown Forest, which was well wooded with large beech trees. The ironmasters appear to have been rather careless in using this wood and it was a particular cause of annoyance to Lord Abergavenny that they had ignored the proviso of the indenture of 1562 which prohibited the felling of great trees where gosshawks (the largest of hawks) and lanners (small falcons) had their breeding places. In addition, the ironmasters refused the use of the furnace during the five foundays reserved to the Lord's use by the indenture. When, on the 21st of November, 1568, Lord Abergavenny sent his workmen to work the furnace they were hindered by the ironmasters with the help of "*lewd and evil disposed persons*" some of whom in "*warlike and riotous manner*" had their "*bowes bent and arrowes ready*," and others "*having ready great shovels filled with hot burning cole* (*i.e.*, coal) *and sinder*" to cast them at the Lord's servants.[8] On the 12th of January, 1569, another incident occurred : when Lord Abergavenny's servants tried to stay the cutters of trees, they were attacked by the French founder and five others of the workers of Cowford furnace "*with eleven feet long piked staves.*" Consequently, the Lord lodged a complaint at the Court of the Star Chamber.

This was evidently the end of Relfe's and Jeffrey's activities as ironmasters at Cowford. In 1574, Bartholomew Jeffrey had Lord Buckholt's furnace and forge at Buckholt, in the parish of Bexhill in Sussex. Jeffrey also was an ironmonger living in Battle. When he died early in 1575, he was in debt.[9] More prosperous appeared to be his partner William Relfe. In 1574, he worked a furnace at Heathfield in Sussex.[10] His later activities also extended into South Wales. In Glamorganshire he had a share in a forge in the parish of Llanwonno and in a furnace which is supposed to have been at Pontygwaith in the Taff valley south of Merthyr Tydfil ; he died some years before 1590.[11]

The French founder Bignall also left the district. In his later days, however, he appeared to show no further symptoms of his former "*warlike and riotous manner.*" In 1577, he married at Horsham, raised a family and lived there apparently quite peacefully until his death in 1603.[12]

[1] Public Record Office, Star Chamber, Elizabeth; A, Bundle II, No. 25.

[2] Documents of Lord de l'Isle and Dudley preserved at Penshurst Place, Kent, No. 378/13.

[3] *Ibid.* Nos. 378/15 and 16.

[4] E. Straker, Wealden Iron, p. 256, London 1931, stated that "*the only record of this furnace*" is contained in a Note of 1603.

[5] *Ibid.*, p. 257.

[6] Straker, *loc. cit.*, pp. 254, 275. Nicholas Fowle is mentioned in the parish registers of Frant from 1556 to 1571. As he had a daughter baptised in 1556, he cannot possibly be identical with the ironmaster of the same name who died in 1634 according to Straker, *loc. cit.*, p. 276.

[7] E. C. Curwen, The Archaeology of Sussex, pp. 258–259, London 1938. See also S. E. Winbolt, Excavations at Saxonbury Camp, Sussex Archaeological Collections, vol. LXXI, pp. 230–231, Cambridge, 1930.

[8] Public Record Office, Star Chamber, Elizabeth; A, Bundle II, No. 25.

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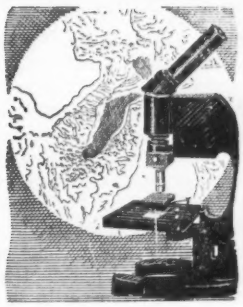
BRITISH IRON AND STEEL RESEARCH ASSOCIATION



A Period Immersion Pyrometer

By R. F. Wright and E. Scorah

SYNOPSIS

A method of period immersion pyrometry has been developed for use on high-frequency furnaces using normal types of immersion pyrometer fitted with fused alumina dipping tubes, which are coated with alumina cement to minimize heat shock. Immersion periods of up to two hours have been obtained.

Experiments in other uses of the technique are mentioned. An appendix by T. Land and R. Barber describes an alternative method of thermal shock protection by enclosing the alumina tube in a steel sheath.

DEVELOPMENT OF TECHNIQUE

A MORE effective control of liquid steel temperatures would be achieved if the necessarily brief immersion period of the quick immersion pyrometer was extended, and experiments have therefore been carried out over the past two years to extend the immersion time.

In early experiments a record of an 80-minute immersion, in pig iron under a vacuum at 1400° C., was obtained by using a silica dipping tube but under more rigorous conditions the tube failed before any temperature reading was obtained; under such conditions the only alternative was found to be recrystallized fused alumina.

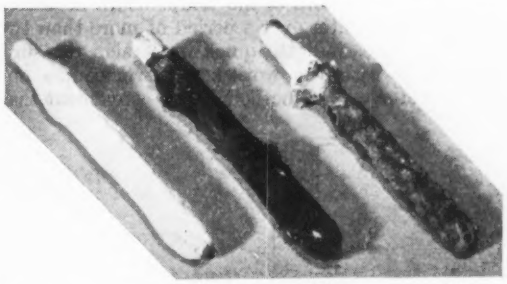
The logical solution to the heat-shock problems common to this material was a coating of some material to delay increase in temperature of the tube. Alumina cement was found to be most satisfactory for this purpose. Another method of reducing the thermal shock on the sheath is described in the Appendix.

In laboratory experiments over a temperature range of 1350° C. to 1700° C., one tube withstood an immersion period of 2 hr., a minimum of slag being present on the bath. Later experiments on a high-frequency production furnace of 5 tons capacity showed that a coating, $\frac{1}{8}$ in. thick, of alumina cement was sufficient to protect the tube against the shock of introduction into metal at about 1600° C. without preheating it, whereas thicker coatings delayed overmuch the attainment of maximum temperature. Nevertheless as an additional precaution the pyrometer was suspended for a brief period above the surface of the bath in order to preheat the tube.

Immersion into clear metal with no slag caused little or no erosion of the tube in 20 min., but thin active slags caused pronounced erosion in 5 min. at the slag/metal interface. Depending on conditions of use, therefore, a metal sleeve, a graphite block, or a refractory block was used to accommodate the dipping tube; the block allowed the whole of the exposed portion of the dipping tube to go below slag level and thus prolonged its life.

The Method

Fused alumina tubes measuring 120 × 10 × 6 mm. were coated by rotating them in a thick, creamy mixture of a proprietary alumina cement and water, and then drying them in a vertical position for 12 hr. A second coating was applied to overcome defects due to bubbles or cracks. Figure 1 shows (i) an unused coated tip, (ii) a tube after immersion for 9¾ min.



(i) (ii) (iii)

Fig. 1—Fused alumina tubes after immersion in clear metal

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Mr. Wright and Mr. Scorah are at the Brown-Firth Research Laboratories.

in clear metal, and (iii) a tube showing erosion at the slag line after immersion for 6¾ min. through slag into metal.

The thermocouple was insulated with fused alumina twin-bore insulators and inserted in a heat-resistant tube, the latter being threaded to permit easy change-over from metal sleeve to graphite block according to bath conditions. The immersion temperatures were measured with the usual types of high-speed temperature-recorder and checks were taken with a normal quick immersion pyrometer placed next to the period immersion pyrometer in the bath.

Subsequent laboratory checks showed a tendency towards a fall in e.m.f. representing an error of up to 4° C. after immersion for 20 min.

EVALUATION OF USEFULNESS

Since the introduction of this technique as a routine procedure on two high-frequency furnaces at the begining of December, 1949, several hundred heats have been controlled by this method. The total costs during this period have been no greater for period immersion than for quick immersion. The time taken to reach a desired furnace temperature has been reduced from approx. 10 to 4 min. and the resultant closer control of temperature has yielded a greater uniformity of ingots.

The maximum time of immersion depends on the quality of the steel and the state of the slag, but with this particular usage the tube was normally withdrawn from the bath in good condition.

Other Lines of Development

The coated alumina tube has been used to obtain a complete temperature record in the ladle during the casting of a heat of about 5 tons of steel by floating the thermocouple on the surface of the slag and metal. Much more work must be done in this direction, however, before the value of the results can be assessed.

The coated tube has also been used for high-temperature salt-bath measurement at about 1300° C.; immersion for five days left the tube undamaged.

APPENDIX

An Alternative Method of Thermal Shock Protection

*By T. Land, M.A., F.Inst.P., and R. Barber, B.Sc.**

Wright and Scorah protect the alumina tube from thermal shock by coating the tube with refractory cement. We have obtained the same result by a different method. The alumina tube is enclosed in a hollow block of steel (Fig. 2) which slowly heats up and melts in the liquid steel leaving the alumina tube exposed to the steel.

Figure 3 is a record of the temperature measured with a potentiometer over a period of more than two hr. The crosses indicate quick immersion measurements made with the workshop thermocouple and millivoltmeter. This method is less convenient than the use of coated tubes, but has the advantage that the alumina tube is left in intimate contact with the steel, thus reducing the lag in recording rapidly changing temperatures. In later experiments tube failure occurred at the slag line after intervals varying from 20 to 50 min.

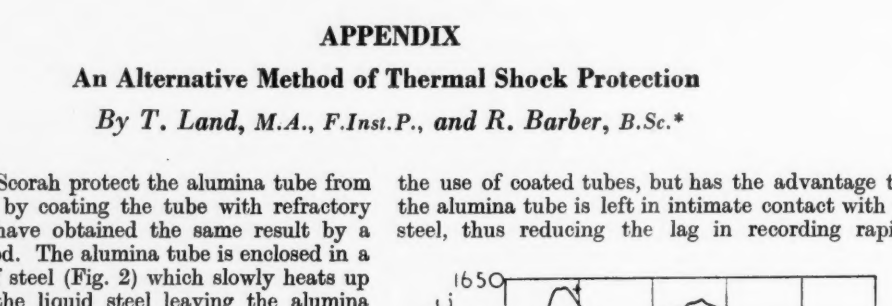

Fig. 3—Record of measured temperature

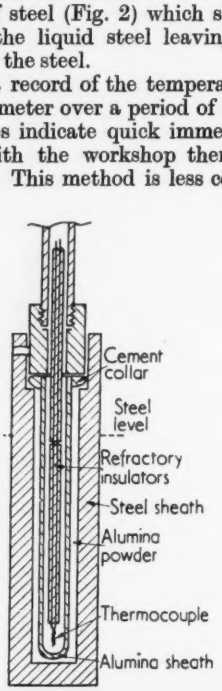

Fig. 2—Assembly of thermocouple protection tube and steel sheath

Acknowledgments

The experiments described in this report were carried out in the Brown-Firth Research Laboratories, and Dr. C. Sykes, F.R.S., Director of the laboratories, is thanked for permission to publish this report.

The work described in the Appendix was carried out at the Research Laboratories of The United Steel Companies, Ltd. Mr. F. H. Saniter and his staff are thanked for making their facilities available, and the staff of the Steelmaking Division of the British Iron and Steel Research Association are thanked for help during the trials.

* Mr. Land and Mr. Barber are with Land Pyrometers Ltd., Sheffield.

Pyrometers for Surface-Temperature Measurement

By M. D. Drury, B.Sc., K. P. Perry, and T. Land M.A., F.Inst.P.

SYNOPSIS

This report describes three improved pyrometers designed to measure the temperature of hot surfaces in cool surroundings, with particular reference to the requirements of the steel industry.

(1) For temperatures above 900° C., the pyrometer incorporates a back-silvered glass hemisphere which allows nearly black-body radiation in the visible wavelengths to escape through a small hole at the top and be measured by a calibrated barrier-layer photo-electric cell.

(2) For temperatures from 300–900° C., the photocell is replaced by a thermopile and the glass hemisphere by a platinum-plated steel one. The effect of different surface emissivities on the calibration of the instrument has been found to be small over a wide range.

(3) For temperatures up to 500° C., radiation is concentrated on a thermocouple at the focus of a plated steel spherical segment. The couple touches the surface but does not rely on perfect contact for accurate surface-temperature measurement.

In 1948 a review was published of possible methods of measuring surface temperatures.[1] Since then, experiments have been continued to produce instruments suitable for measuring surface temperatures of objects such as ingots, ingot moulds, and billets, as well as sheet and strip steel during rolling.

The present paper describes three instruments which have been brought to a stage for testing under works conditions, and sets out the theory of operation together with details of laboratory tests.

THE USE OF REFLECTORS FOR SURFACE-TEMPERATURE MEASUREMENT

Of the three instruments developed, two depend on measuring the radiation from the hot surface and the third is a contact method, using a thermocouple. The errors of both methods can be serious and in order to measure a surface temperature accurately it is necessary to produce a small enclosure that is a full radiator, at the temperature at the point of measurement, in so far as the wavelengths measured are concerned. This has been accomplished by placing a small concave reflector on the surface.

It is shown in Appendix I that the radiation within such a hemispherical reflector approximates closely to black-body radiation at the temperature of the hot surface.

The two radiation pyrometers measure respectively the visible light and the total radiation for all wavelengths emerging from a small hole in the concave reflector. Table I shows the errors in temperature measurement by such methods on surfaces of different emissivities. The 'effective' emissivity of the surface is its apparent emissivity due to the application of the reflector (*see* Appendix I). The reflector is assumed to have a reflectivity of 0·9 and the pyrometer to read correctly for a surface with an emissivity of 0·65.

The effective reflectivity of the hemispherical cap is reduced by the presence of an observation hole in the reflecting surface. It may also be advisable to

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Mrs. Drury and Mr. Perry are on the staff of the Physics Department of the Association. Mr. Land is a Director of Land Pyrometers, Ltd., Sheffield.

Table I

ERRORS IN TEMPERATURE MEASUREMENT BECAUSE RADIATION FROM ENCLOSURE IS NOT PERFECTLY 'BLACK'

Emissivity of Surface	Effective Emissivity	Errors, ° C., Based on True Temperature						
		Visible Radiation (using 0·6 microns)			Total Radiation			
		800° C.	1000° C.	1200° C.	400° C.	600° C.	800° C.	1000° C.
0·4	0·87	−4	−6	−8	−15	−19	−23	−27
0·5	0·91	−2	−3	−4	− 7	− 9	−12	−14
0·6	0·94	0	−1	−1	− 2	− 2	− 3	− 3
0·7	0·95	0	+1	+1	+ 2	+ 2	+ 3	+ 3
0·8	0·98	+2	+2	+3	+ 5	+ 7	+ 8	+10
0·9	0·99	+2	+3	+4	+ 7	+ 9	+11	+13

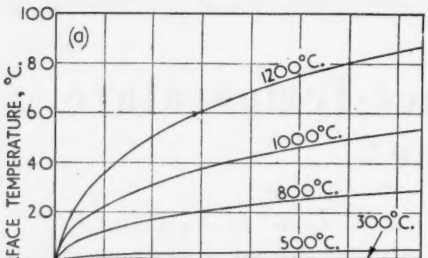

Fig. 1—Variation of the temperature rise at the centre of (*a*) a perfectly insulated 2 in. dia. area for different surface temperatures, (*b*) a perfectly insulated area for insulators of different diameters. Initial surface temperature of 1000 ° C.

leave a small gap between the hemisphere and the hot surface, particularly when convective heating or cooling affects the temperature of the surface significantly. In Appendix II theoretical maxima are obtained for the diameter of the hole and the distance of the hemisphere from the surface that will limit the error caused by the reduction in the reflectivity of the cap to 1%.

In the third instrument, where a thermocouple is placed within a reflecting cap, it is heated on all sides by nearly black-body radiation at the temperature of the hot surface, and eventually almost attains the surface temperature, only being prevented by the cooling effect of the convection currents within the cap. The air inside the cap is heated slowly and the temperature of the thermocouple, after rising rapidly at first, continues to rise more and more gradually.

However, it is possible, with a fine thermocouple, to place the junction within the stagnant boundary layer at the hot surface and thus obtain the true surface temperature. This method is employed in the third instrument.

CHANGE OF SURFACE TEMPERATURE DUE TO THE PRESENCE OF THE INSTRUMENT

A surface of a red-hot steel block cools rapidly in cold surroundings, causing large temperature gradients perpendicular to the exposed surface. When an area is covered by a reflector, the heat loss under it is reduced almost to zero, so that the local temperature of the surface rises.

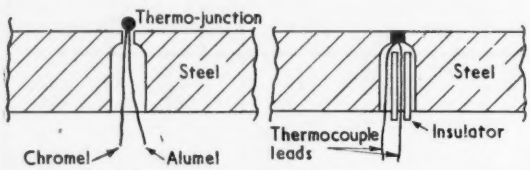

Fig. 2—Diagram of method of peening in surface thermocouple

Appendix III gives a mathematical analysis of this problem in which it is assumed that the surface of the rest of the block is at a constant temperature throughout the periodic application of the reflector. It is shown that if this reflector is left on the surface for a sufficient time, the temperature of the surface at the centre of the covered area will rise to that of points elsewhere inside the block at a depth below the surface equal to the radius of the circular area covered by the reflector.

This temperature rise is considerable, but fortunately it takes several min. to reach its maximum value. Nevertheless, with a pyrometer response-time of about 5 sec., 900–1000° C. represents about the ultimate upper limit of temperature which can be measured accurately by this method, as will be seen from Fig. 1*a*, in which the temperature rise with time is plotted for different surface temperatures for an insulated surface of 2 in. dia. Reducing the diameter of the insulator decreases the total temperature rise, but Fig. 1*b* shows that for a ½-in. insulator the difference during the first $\frac{5}{4}$ sec. is relatively small. However, the irregular

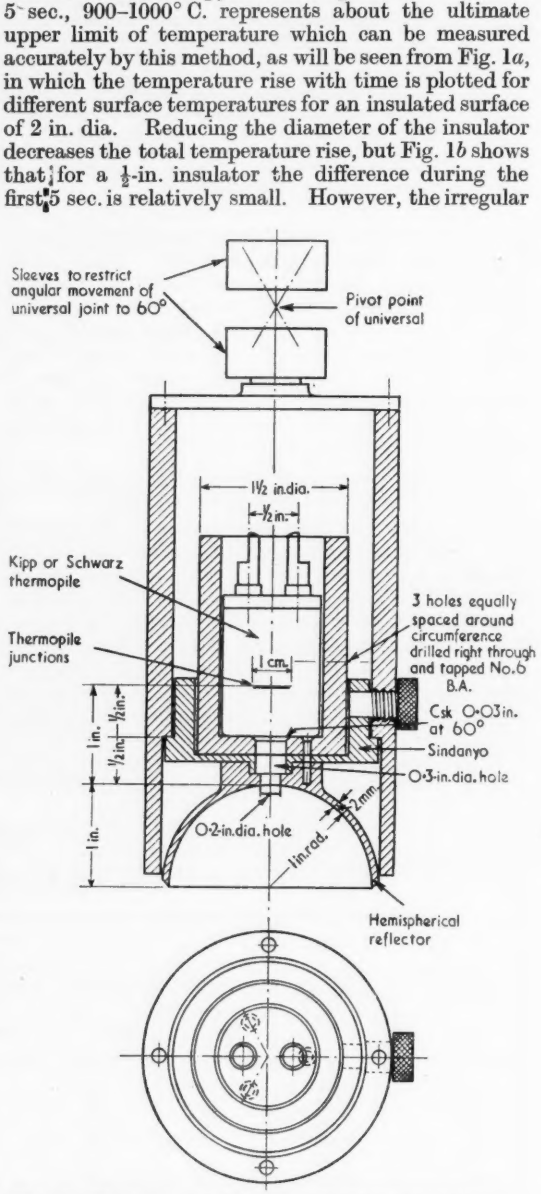

Fig. 3—Diagram of plated hemisphere pyrometer

surfaces likely to be encountered in industrial measurements would make it difficult to use reflectors much less than 2 in. dia.

The use of a total radiation pyrometer with a reflector seems practicable for measuring surface temperatures of materials cooling in free space up to 900° or 1000° C., but above this temperature it is necessary to avoid reflecting the radiant heat back to the surface at the point of measurement.

At about 900° to 1000° C. a hot body begins to emit a measurable quantity of visible light, and it is possible to reflect only radiation of visible wavelengths to the surface whilst absorbing the major part of the radiant heat in a suitable glass screen. With a selenium barrier-layer cell a very rapid reading of the visible light can be taken and surface temperatures up to 1200° C. can be measured without causing a serious rise.

The best glass would be Chance's ON 19, which absorbs nearly all the infra-red radiation, if a hemispherical shell, silvered on the outer surface, could be made from it. However, it is not easy to obtain such shapes in this type of glass, and the first instrument has been made on this principle but using Pyrex glass for the reflector.

The proportion of radiant energy reflected by such a silvered reflector is shown as follows :

° C.	Proportion Reflected Back
1200	46%
1100	41%
1000	36%
900	31%
800	27%

In the calculations it has been assumed that 95% of the radiation is transmitted up to 2·8 microns and 20% beyond this wavelength. With Pyrex glass, if a reading could be obtained in two seconds, the temperature rise would be only 5° C. at 1000° C. and 10° C. at 1200° C.

It would be possible to improve the method still further by introducing a sheet of ON 19 glass at the base of the hemisphere, or by using a water-cooled, two-walled hemisphere with the outer surface of the larger hemispherical surface silvered.

EXPERIMENTAL RESULTS

The pyrometers were tested on a ½-in. thick electrically heated steel block, temperatures up to 900° C. being obtained. The true surface temperature was measured by a chromel–alumel thermocouple peened into the surface from the back of the plate as shown in Fig. 2.

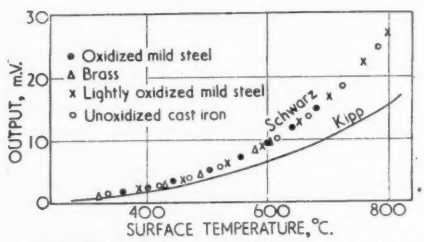

Fig. 4—Calibration of surface pyrometer using Schwartz thermopile on different metal surfaces. Lower curve shows comparison with Kipp thermopile

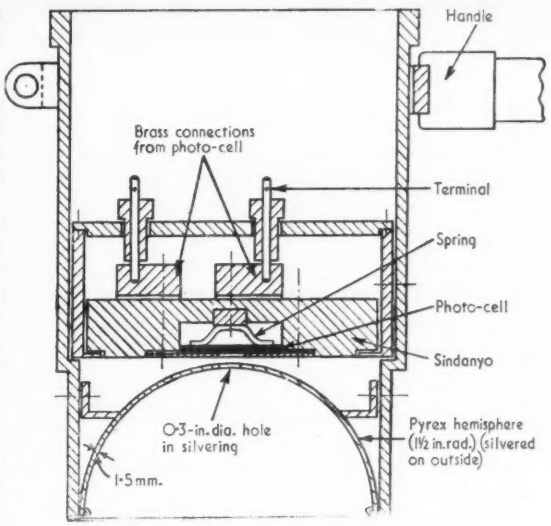

Fig. 5—Diagram of Land pyrometer

Total Radiation Pyrometer with Reflector

This pyrometer, shown in Fig. 3, consists of a thermopile, which receives radiation through a small hole 0·2 in. dia. at the top of a steel hemisphere of 1 in. radius.

The steel hemisphere of the prototype instrument was plated with platinum to give a reflectivity of 0·95 but other surfaces may also be suitable. In the first experiments a Hilger Schwartz vacuum thermopile was used. This has the advantages of quick response and high sensitivity, but it is also very sensitive to changes in ambient temperature. As an alternative a Kipp thermopile has been used. This is rather slower (3–5 sec.) in response and has a smaller output but may well prove quite satisfactory for general purposes.

(*a*) *Effect of surface emissivity*—This pyrometer has been tested for calibration on different surfaces, and for its effect on the surface temperature at the point of measurement. The surfaces used and their total emissivities* were as follows : lightly oxidized mild steel, 0·50 ; oxidized mild steel, 0·79 ; cast iron, 0·80 ; brass, 0·59.

The calibration results using the Schwartz thermopile shown in Fig. 4 confirm that the readings are

* The values for total emissivity quoted are those given in ref. (2) and are only approximate.

Table II

RISE IN TEMPERATURE OF SURFACE AFTER APPLICATION OF PYROMETER

Temperature before Application of Pyrometer, ° C.	Rise, ° C.		
	After 5 sec.	After 10 sec.	After 15 sec.
300	1	1	2
500	2	2	3
800	8	9	14

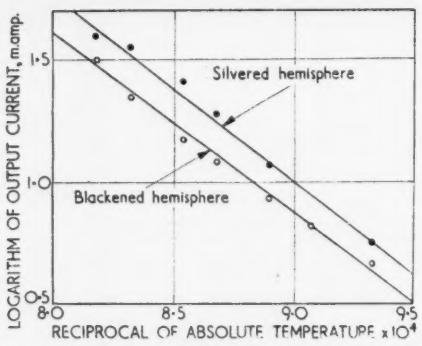

Fig. 6—Calibration characteristics of photoelectric pyrometer

nearly independent of surface conditions over a wide range of emissivities.

A comparison calibration curve of the pyrometer using a Kipp thermopile is also shown.

(*b*) *Effect of pyrometer on surface temperature*—The measured rise in surface temperature of the steel calibrating block resulting from the application of the pyrometer, is shown in Table II.

The results agree with the theoretical values (Fig. 1) up to about 500° C. whilst above that temperature they are rather lower. This suggests an emissivity value a little lower than 0·7 for the calibrating surface.

(*c*) *Effect of change of reflectivity of hemisphere*—It was found that the platinum plating deteriorated with use as did rhodium, whilst gold completely disappeared after only a few seconds. This difficulty was overcome without any measurable effect on the calibration of the instrument, by applying a very thin coating of silica to the platinum plating.

Photoelectric Pyrometer with Silvered Glass Reflector

The experimental pyrometer is illustrated in Fig. 5. The reflector is a hemispherical shell of Pyrex glass 3 in. dia. and 1·5 mm. thick, silvered on the outer surface except for an area at the top of 0·3 in. dia., through which visible radiation falls on a selenium barrier-layer photocell.

To confirm that the reflector does increase the intensity of radiation from the hot surface a block of steel heated in a furnace to 1000° C. was allowed to cool in air, alternate readings being taken with the glass hemisphere pyrometer and an optical pyrometer. The inner glass surface of the reflector was then coated with indian ink and the experiment was repeated. In the second experiment there was little or no light reflected to the surface. The results, plotted in Fig. 6, indicate that the readings without are less than those with the reflector by about 25%, which agrees with the expected value of about 0·75 for the surface emissivity.

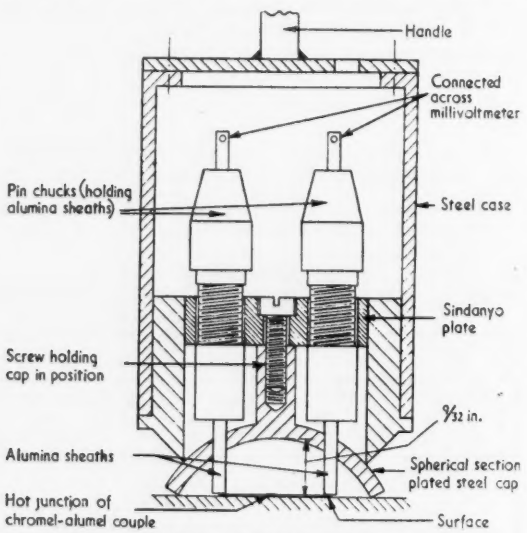

Fig. 7 Diagram of plated cap pyrometer

Contact Thermocouple Pyrometer with Reflector

This instrument, shown in Fig. 7, employs a chromel–alumel couple of which the junction and about 0·25 in. of wire on either side of it are close to the surface. The junction of the couple is approximately at the focus of a platinum-plated spherical steel cap of height $\frac{9}{32}$ in.

The couple in this instrument receives reflected radiation on all sides from the plated cap surrounding it and does not solely rely on perfect contact with the surface for accurate measurement.

It was found necessary for fine-gauge thermocouple wires (36 S.W.G., butt-welded junction) to be used to obtain a rapid and accurate reading, and for the thermocouple to touch the hot surface although no special care need be taken to press it into place.

A representative curve given in Fig. 8*a* shows that after 30 sec. the pyrometer indicated the true temperature, but that afterwards there was a steady creep in the thermocouple temperature, comparable with the rise in the surface temperature caused by the application of the pyrometer. A typical curve

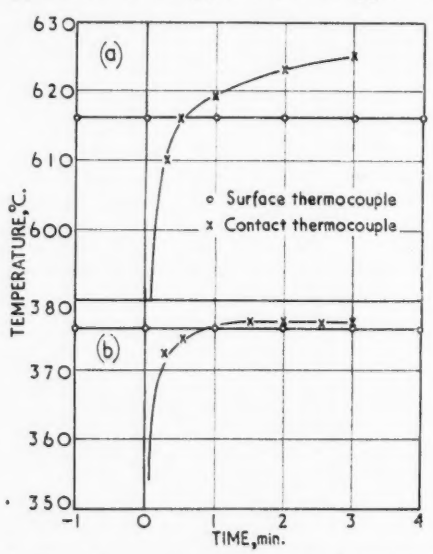

Fig. 8—True-temperature curves of pyrometer with 36 S.W.G. butt-welded couple and platinum-plated cap, for different initial temperatures

of experiments in the lower temperature range 350–400° C. is shown in Fig. 8*b*.

CONCLUSIONS

Each of the three pyrometers described appears to be most suitable for a particular temperature range. For low temperatures up to perhaps 500° C. the contact thermocouple with a reflecting cap is most suitable because of larger output, although it is more delicate and more easily damaged than the other instruments. From 400° C. to 900° C. the total radiation pyrometer gives quick and accurate readings ; above 900° C. the photoelectric unit gives the best results.

Acknowledgments

The work described in this paper was carried out on behalf of three committees of the British Iron and Steel Research Association : the Thermal Treatment Sub-Committee of the Metallurgy Division ; the Fuel Committee of the Plant Engineering Division ; the Pyrometry Sub-Committee of the Steelmaking Division.

APPENDIX I—The Effective Emissivity of a Surface Covered by a Reflecting Hemisphere

Let the total emissivity and reflectivity of a surface at temperature T be E_s and R_s respectively. Then by Kirchoff's Law :

$$E_s + R_s = 1$$

If the reflectivity of the reflector is R_r then the radiation I reflected to the surface is :

$$I = R_r Q$$

where Q is the sum of the radiation emitted and reflected by the hot surface.

Now the radiation emitted by the surface is $E_s \sigma T^4$ where σ is Stefan's constant.

Hence :

$$Q = E_s \sigma T^4 + R_s I$$

Eliminating I and writing $R_s = 1 - E_s$,

$$Q = E_s \sigma T^4 + (1 - E_s) R_r Q$$

$$\therefore Q = \frac{E_s}{1 - R_r(1 - E_s)} \sigma T^4$$

This is the intensity radiation that would emerge from a small hole in the reflector. If the reflector is perfect and R_r is unity, Q is equal to σT^4, that is, black-body radiation at the temperature of the surface, and I has the same value.

If R_r is less than unity then

$$\frac{E_s}{1 - R_r(1 - E_s)}$$

may be considered to be the effective emissivity of the hot surface with a reflector. For example, a reflector of reflectivity 0·90 increases an emissivity of 0·65 to an effective value of 0·95.

APPENDIX II—The Effect of the Observation Hole and of a Gap between the Reflector and the Surface

The radiation at the centre of the hemisphere emitted in unit time by an area δA of the surface in the solid angle between cones of angles $2(\theta + \delta\theta)$ and 2θ is

$$\delta W = \frac{I \delta A \cos\theta . 2\pi R \sin\theta . R \delta\theta}{R^2}$$

$$= I\pi \sin 2\theta . \delta\theta . \delta A .$$

where I is the quantity of radiation emitted normal to the surface, per unit area, per unit solid angle, per unit time, and R is the radius of the hemisphere.

The total radiation emitted is

$$W = \int_0^{\pi/2} I\pi\delta A \sin 2\theta . d\theta$$

$$= I\pi\delta A .$$

If the circular area at the top of the hemisphere has a radius r and subtends an angle θ_1 at the centre of the hemisphere, the radiation passing through the circular area will be

$$\delta W_1 = \int_0^{\theta_1} I\pi\delta A \sin 2\theta . d\theta$$

$$= I\pi\delta A \sin^2\theta_1$$

$$= I\pi\delta A . \frac{r^2}{R^2}$$

since $r = R \sin\theta$, and therefore

$$\frac{\delta W_1}{W} = \frac{r^2}{R^2} .$$

If the hot surface has an emissivity of 0·65 and the reflector has a reflectivity of 0·90 then a hole with a radius equal to $\frac{3}{20}$ of the radius of the hemisphere will reduce the measured radiation by 1%.

Similarly, if the gap d between the hemisphere and the surface subtends an angle θ_2 at the centre, the radiation passing through the gap is

$$\delta W_2 = \int_{\pi/2\theta_2}^{\pi/2} \pi I \delta A \sin 2\theta . d\theta$$

$$= I\pi\delta A \sin^2\theta_2$$

since $\sin\theta_2 = d/R$, and therefore

$$\frac{\delta W_2}{W} = \frac{d^2}{R^2} .$$

If the hot surface has an emissivity of 0·65 and the reflector has a reflectivity of 0·90 then a gap equal to $\frac{3}{20}$ of the radius of the hemisphere will reduce the measured radiation by 1%.

APPENDIX III—The Increase in Surface Temperature after Application of a Perfect Reflector (or Perfect Insulator)

The problem is to determine the effect of eliminating entirely or partially by means of a reflector the heat loss over a finite circular area of surface of a semi-infinite solid at temperature T and of emissivity E, radiating to cold surroundings.

It must be assumed that none of the heat reflected to the surface is lost by increased radiation elsewhere on the surface, although this is not strictly true ; the effect will be to make the calculated rise in surface temperature under the reflector only slightly larger than the actual temperature increase.

This problem then becomes identical with that of an infinite solid containing in the plane $z = 0$ a

uniform circular heat source of $2E\sigma T^4$ heat units per unit area, which begins to operate at time $t = 0$.

The solution has been given by Carslaw and Jaeger[3] of the corresponding problem of an instantaneous plane circular source at time $t = 0$. The equation for the temperature θ at the centre of the circular area at time t after the operation of an instantaneous source of strength q, is given by

$$\theta = \frac{q}{2\sqrt{\pi D t}}\left\{1 - e^{-\frac{a^2}{4Dt}}\right\};$$

q is here in units of temperature, not heat, D is the thermal diffusivity of the solid and a is the radius of the circular area. To obtain the solution for the continuous heat source, q is replaced by

$$\frac{2E\sigma T^4}{\rho c}$$

where ρ and c are the density and the specific heat of the solid; the expression is then integrated between the limits 0 and t, giving :

$$\theta = \frac{E\sigma T^4}{\rho c\sqrt{\pi D}}\int_0^t\left(1 - e^{-\frac{a^2}{4Dt}}\right)t^{-\frac{1}{2}}dt.$$

To evaluate this integral the substitution

$$x^2 = \frac{a^2}{4Dt}$$

is made and the equation obtained is

$$\theta = \frac{aE\sigma T^4}{\rho cD}\cdot\frac{1}{\sqrt{\pi}}\int_{\frac{a}{2\sqrt{Dt}}}^{\infty}(1 - e^{-x^2})x^{-2}dx.$$

Now ρcD is equal to the thermal conductivity k of the solid, and

$$\frac{E\sigma T^4}{k}$$

is equal to the temperature gradient dT/dz perpendicular to the surface.

$$\therefore \quad \theta = a\frac{dT}{dz}\frac{1}{\sqrt{\pi}}\int_{\frac{a}{2\sqrt{Dt}}}^{\infty}(1 - e^{-x^2})x^{-2}dx.$$

This can be integrated by parts giving

$$\theta = a\frac{dT}{dz}\left\{1 - \mathrm{Erf}\left(\frac{a}{2\sqrt{Dt}}\right) + \frac{2}{a}\sqrt{\frac{Dt}{\pi}}\left(1 - \exp.\left(-\frac{a^2}{4Dt}\right)\right)\right\}.$$

The terms inside the bracket become equal to unity for large values of t, so the temperature rise θ at the centre of the area covered by the reflector eventually reaches the steady value adT/dz and the temperature becomes equal to the temperature at a depth below the surface equal to the radius a of the circular area covered by the reflector.

Typical curves deduced from the last equation are shown in Figs. 1 and 2 for mould steel with :

emissivity = 0·7
diffusivity = 0·0625 sq.cm./sec.
conductivity at 300° C. = 0·10 cal./sq.cm./sec./° C.
500° C. = 0·09 ,, ,, ,, ,,
800° C. = 0·059 ,, ,, ,, ,,
1000° C. = 0·064 ,, ,, ,, ,,
1200° C. = 0·071 ,, ,, ,, ,,

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Interim Report of Service Trials of Steel Coal Wagons (1939–1950)

By J. C. Hudson, D.Sc., F.I.M.

SYNOPSIS

Service trials have been in progress since 1939 on floor plates of four different compositions built into 100 steel coal wagons belonging to British Railways. Observations over the first ten years indicate that the life of the plates should be about 25 years in mild steel but that this life should be at least doubled by the use of copper-bearing steel or low-alloy steels of the copper–manganese or the copper–chromium type. The author concludes that the superstructure of coal and mineral wagons should be built of copper-bearing or low-alloy steels.

THIS is an interim report of service trials of the following four types of steel plate built into the floors of 100 steel coal wagons : (i) ordinary mild steel, (ii) low-copper steel, (iii) copper–manganese steel, and (iv) copper–chromium steel. The trials were arranged in 1938 by a Panel of the Corrosion

Paper MG/BB/57/50 of the Atmospheric Corrosion Sub-Committee of the Metallurgy (General) Division of the Association, received 11th April, 1951. The views expressed are the author's and are not necessarily endorsed by the Committee as a body.

Dr. Hudson is Head of the Corrosion Laboratory of the Association.

Table I

AVERAGE ANALYSES OF THE STEEL PLATES*

Types of Steel	C, %	Mn, %	Si, %	As, %	P, %	S, %	Cr, %	Cu, %	Ni, %
Mild steel	0·19	0·46	0·024	0·09	0·021	0·037	<0·02	0·07	0·04
Copper steel	0·17	0·56	0·026	0·04	0·037	0·040	<0·04	0·35	0·01
Copper–manganese steel	0·19	1·34	0·208	0·04	0·051	0·051	<0·08	0·44	0·01
Copper–chromium steel	0·25	0·84	0·045	0·03	0·028	0·039	0·90	0·33	0·03

* The mild steel and the copper steel comply with B.S. 15 : 1948. The copper–manganese steel and the copper–chromium steel approximate to the requirements of B.S. 968 : 1941, which was not in existence when these casts were made

Committee,* and have already been in progress for 11 years.

ARRANGEMENT OF THE TRIALS

Particulars of the Steels

The manufacture of the steels is described in Appendix I and average analyses of the plates are given in Table I. The results of a metallurgical examination are reported in Appendix II.

Manufacture of the Wagons

The wagons concerned are of the 20-ton side-discharge type (*see* Fig. 1). Their floors consist of four ¼-in. thick steel plates, inclined at 45°, and welded together along their apices. There is a transverse central division of mild-steel plate. One plate of each steel was built into each wagon. There are 12 possible arrangements of four different plates in the floor and to minimize any positional effect that might result from loading the wagons at one end, each arrangement of four different plates was used for eight wagons; the arrangements for the remaining four wagons were selected at random.

Service Observations

Since the wagons went into service between July and December, 1939, on the average, each has transported more than 20,000 tons of coking slack and has travelled more than 50,000 miles; during return journeys the wagons were empty. From 1946 onwards the moisture content of the slack was 9–10%; before this the average value was about 8%.

Although the Instruments Section of B.I.S.R.A. is endeavouring to devise a non-destructive tester for measuring the thickness of the plates, the high degree of accuracy necessary to distinguish between the respective wastages has not yet been achieved. At inspections in the field it has, therefore, been necessary to rely on visual observations of the wagons coupled with micrometer measurements of the thickness of the plates at about ½ in. from the bottom edge, where they are accessible.

Inspections have been made of random samples of 10 or 12 wagons marshalled at half-yearly intervals for the first eight years and thereafter once a year. The lower surfaces of the floor plates were painted at the works and are sheltered from the rain; no serious corrosion has occurred here. A layer of scaly rust and coal dust soon formed on the upper surfaces in contact with the coal. This layer grew to a thickness of more than 0·1 in. after four years but flaked off at intervals over large areas because of impact or abrasion. Occasionally granular instead of scaly rust was noticed on a few plates but this fact could not be connected with the composition of the steel and, in general, no striking difference between the steels has been observed.

The formation of scaly rust led to a steady increase in the thickness of the plates at the edge (*see* Fig. 2). The average value of about 40 determinations rose from 0·25–0·26 in. to a maximum of 0·30–0·33 in. after five to seven years; thereafter the thickness decreased and after ten years it was 0·23–0·24 in. Since these thickness measurements include the thickness of the rust on the upper surface, their significance is limited, but Table II shows that the decrease after ten years was greatest (0·024 in.) for the mild-steel plates. No distinction was justifiable between the three low-alloy steels; the average decrease for all of them was 0·012 in.

QUANTITATIVE RESULTS

The routine determinations of the thickness of the edges of the plates are of limited accuracy, and a much longer time will have to elapse before they yield a significant distinction between the wastages of the different steels. Measurements of plate thickness

* The Corrosion Committee was originally a Joint Research Committee of The Iron and Steel Institute and the British Iron and Steel Federation. It now forms part of the British Iron and Steel Research Association.

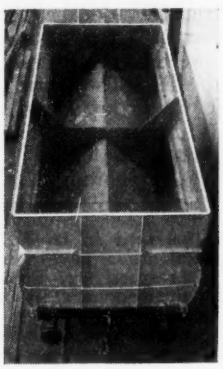


Fig. 1—20-ton side-discharging coal wagon

Table II

APPARENT LOSS IN PLATE THICKNESS AT THE LOWER EDGE AFTER TEN YEARS' SERVICE

(Micrometer Measurements)

Type of Steel	Average Thickness, mils		
	Initial	After Ten Years	Loss
Mild steel	255	231	24
Copper steel	244	229	15
Copper–manganese steel	246	241	5
Copper–chromium steel	257	241	16

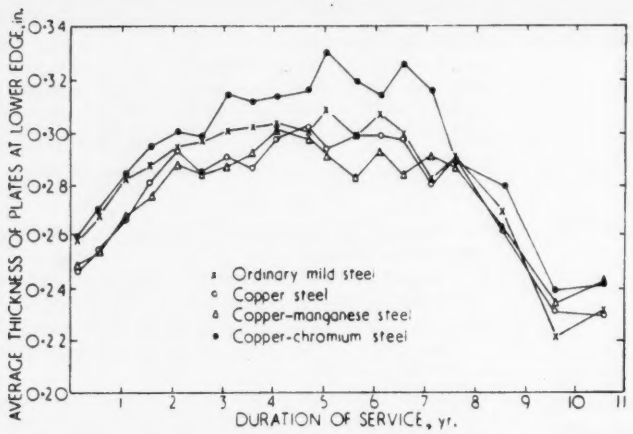


Fig. 2—Variation in apparent thickness at the lower edge of the plates

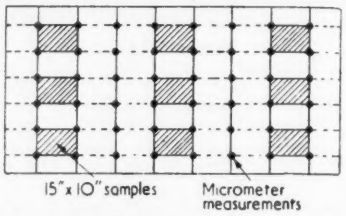


Fig. 3—Method of cutting up the plates after 7½ years

were, therefore, made by other methods after 7½ and 10 years' service, respectively.

Loss in Weight and Thickness Determinations after 7½ years

In 1947 the floor plates were cut from a single wagon selected at random. Each plate was sheared into seven strips, 15 in. wide, as shown in Fig. 3. Flaky rust was removed by hammering and wirebrushing but the intact paint was left on the underside. Micrometer measurements were taken at 10-in. intervals along both edges of the strips and along the inner edges of the discards, and nine samples, each 10 in. wide, were sheared from the 15-in. strips (*see* Fig. 3). The average thickness of each sample was calculated from its weight* and the average of these values for each sheet was compared with the corresponding initial values. These initial values were obtained by extrapolating back to zero time the values of the thicknesses observed at the edges at the first three inspections; 3 mils were subtracted to allow for the paint on the undersides of the plates. The thickness of a plate at the edge may differ from its average thickness; moreover, there will be some deviation in the thickness of individual plates. These factors will introduce errors into the calculations, but a statistical study of the data showed that it is reasonable to assume that these errors do not exceed 3–5 mils.

Table III

RESULTS OF OBSERVATIONS AFTER 7½ YEARS' SERVICE

Type of Steel	Total Wastage, mils		Rate of Wastage, mils/yr.	
	Micrometer Measurements	From Loss in Weight	Micrometer Measurements	From Loss in Weight
Mild steel	31	40	4·2	5·4
Copper steel	6	16	0·8	2·1
Copper–manganese steel	7	13	0·9	1·7
Copper–chromium steel	13	20	1·7	2·6

Contour diagrams, showing the variation in thickness over each of the four plates, were drawn from the micrometer measurements. All four diagrams were similar and Fig. 4, showing the average wastage of all four plates, has been derived from them. Wastage is least near the centre and greatest over a small approximately triangular area (3 sq. ft.) at the outer bottom corner. Its existence may be associated with the way in which the coal flows from the wagon when discharged. The average wastages of the plates deduced from the micrometer measurements and from the losses in weight, respectively, are given in Table III. The figures obtained by the micrometer are lower, mainly because rust removal was necessarily less thorough. Both sets of results, however, agree in showing that the low-alloy

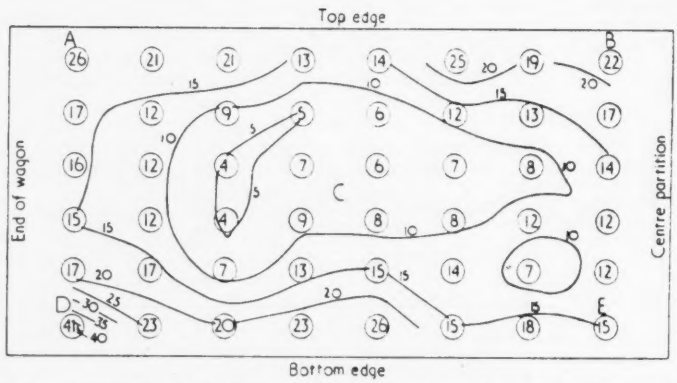


Fig. 4—Wastage of steel floor plates of coal wagons after 7½ years' service (average values for all four types of steel)

* The specific gravity of all the steels was assumed to be 7·84. Laboratory determinations gave values of 7·83 and 7·87, respectively, for mild steel and chromium–copper steel similar in composition to the wagon plates. A correction for the rust on the plates was applied; this was deduced by derusting some of the samples in an acid bath containing an inhibitor.

Table IV

PLATE THICKNESS AFTER 11 YEARS' SERVICE
(Micrometer Measurements)

Wagon No. 231,...	Thickness, mils																					
	Mild Steel						Cu Steel						Cu-Mn Steel						Cu Cr Steel			
	A	*B*	*C*	*D*	*E*	Average	*A*	*B*	*C*	*D*	*E*	Average	*A*	*B*	*C*	*D*	*E*	Average	*A*	*B*	*C*	*D*	*E*	Average
291	253	239	246	211	235	237	247	233	262	235	227	241	233	250	268	221	246	244	256	243	272	226	238	247
306	201	209	194	194	210	201	223	229	248	216	226	229	249	230	262	233	231	241	238	224	256	221	255	239
318	230	232	248	210	231	230	247	227	264	230	230	239	251	230	269	220	232	240	243	243	271	217	242	243
333	224	217	259	217	245	232	260	213	263	229	239	239	248	219	261	223	237	237	242	229	267	228	249	243
Average	227	224	237	208	230	225	244	226	259	227	228	237	245	232	265	224	236	241	244	235	267	223	246	243

Table V

ANALYSES OF WATER DRAINED FROM THE COAL WAGONS AT THE COLLIERIES*

	Bowburn Colliery	Dean and Chapter Colliery
*p*H value	7·8	8·0
Alkalies (Na_2O), p.p.m.	1075	844
Basic oxides (R_2O_3), p.p.m.	2·0	2·0
Lime (CaO), p.p.m.	208	84
Magnesia (MgO), p.p.m.	79	28·1
Carbonate (CO_2), p.p.m.	190	97
Chloride (Cl), p.p.m.	880	220
Silica (SiO_2), p.p.m.	2·4	2·4
Sulphate (SO_3), p.p.m.	501	840
	2935	2117
Oxygen equivalent to chloride	198	50
∴ Total dissolved solids	2737	2067
Probable Constitution of Dissolved Solids, p.p.m.		
Calcium carbonate ($CaCO_3$)	371	150
Magnesium carbonate ($MgCO_3$)	51	59
Magnesium sulphate ($MgSO_4$)	163	...
Sodium chloride (NaCl)	1452	363
Sodium sulphate (Na_2SO_4)	696	1491
Silica (SiO_2)	2	2
Other basic oxides (R_2O_3)	2	2
	2737	2067

* By courtesy of the Central Research Department of Messrs. Dorman Long and Co., Ltd.

steels have resisted corrosion and wear better than the ordinary steel. No distinction between the three different low-alloy steels is justified.

Thickness Determinations after Eleven Years

Further determinations of plate wastage were made in 1950, after nearly 11 years' service, on eight wagons, by drilling five holes in the bottom plates at the positions *A*, *B*, *C*, *D*, and *E* in Fig. 4.

A selection of the individual results is given in Table IV to illustrate the degree of variation from one point or plate to another. Considered as a whole, the results showed the same general distribution of wastage as the earlier determinations and confirmed the broad conclusion that it is an advantage to use low-alloy steels instead of mild steel for coal-wagon floor plates. Again no distinction could be made between the three types of low-alloy steel.

INTERIM CONCLUSIONS

The following conclusions are drawn from the observations to date :

Probable Life of the Floor Plates

The wastage of the floor plates is not excessive and they should have a satisfactory life. For mild steel the average reduction in thickness over 7½ years (deduced from the loss-in-weight determinations, which are more reliable) was at the rate of 5·4 mils/yr. If it is assumed that perforation will occur when the average thickness has been reduced to 100 mils, the probable life of these ¼-in floor plates of ordinary mild steel will be (250—100)/5·4 or about 28 years. Alternatively, from the contour lines of the mild-steel plate cut up after 7½ years (*see* p. 252), it was deduced that the maximum wastage (at the outer bottom corner) was roughly 75 mils. At this rate, 10 mils/yr., a ¼-in. plate would waste away completely at the corner in 25 years. It is probable, therefore, that the life of the mild-steel floor plates will be about 25 years.

Table VI

COMPARISON OF FLOOR PLATES OF ORDINARY MILD STEEL AND OF LOW-ALLOY STEELS

Method of Measurement	Test Duration Years	Total Wastage, Mils		Ratio *B*/*A*, %
		Mild Steel (*A*)	Low-Alloy Steels (*B*)	
Micrometer readings at lower edge	10	24	12	50
Loss in weight	7·5	40	16	40
Micrometer	7·5	31	8	26
Micrometer	10·8	30	10	33

This rate of corrosion is less than might have been expected for mild steel in contact with coal. A possible explanation is that the water draining from the coal is alkaline (*see* Table V). Two analyses are given, which relate to water draining from wagons filled with coal at Bowburn Colliery and at Dean and Chapter Colliery respectively, the two main collieries from which the coal has been transported to the Cleveland Works during the trials. The coal is coking slack and all of it is washed. The analyses show that both waters contain large quantities of dissolved salts, 0·2 or 0·3%, and that both are alkaline* : aqueous extracts of rust samples from the floor plates were also alkaline (*see* Table VII).

When coals are washed it is necessary that the washing water should be alkaline, to protect the washing plant itself from corrosion. Some washed coals are sprayed with lime-treated water before being loaded into wagons. Coal itself suffers chemical changes on atmospheric exposure, although these mainly occur if pyrites is present, weathering of which gives rise to iron sulphates and leads to acidity. Consequently water percolating from tips and dumps may be acid. The water draining from the wagons under test becomes less alkaline in transit from the collieries to the coke ovens—the *p*H of water draining from wagons at the Cleveland coke ovens was found to be 7·1 for coal from Bowburn Colliery and 6·6 for coal from the Dean and Chapter Colliery, whereas, as shown in Table V, determinations made at the collieries gave values of 7·8 and 8·0, respectively.

A white incrustation has sometimes been noticed at the edges of the plates and doors of the wagons. This was found to contain about 46% of sodium sulphate and 17% of free carbon derived from the coal. The remainder consisted of iron oxides, sodium chloride, calcium and magnesium salts ; in fact the whole analysis corresponded fairly closely with that of the dissolved matter in the water draining from the coal wagons at the Dean and Chapter Colliery.

Comparison of Ordinary Steel and Low-Alloy Steels for Floor Plates

All the results agree in showing that the wastage of the low-alloy steel floor plates is little more than one-third of that of the ordinary mild-steel plates (*see* Table VI). In no case, however, do the results permit of a significant distinction between the three different types of low-alloy steel.

For practical purposes it may be assumed that the life of the low-alloy steel plates should be at least double that of ordinary mild-steel plates. This conclusion might be vitiated if low-alloy steels were more liable to local attack than ordinary mild steel, but this is improbable because no visual difference has been observed between the types of rust formed on the plates.

It has been argued that comparisons between the plates should be made at the most corroded point, which is the lower outer corner. The nearest place to this at which measurements were made is point *D* (*see* Fig. 4). From the detailed results it can be deduced that the average wastage at this point over 10·8 years was 47 mils for mild steel, but only 24, 24, and 32 mils, respectively, for the three low-alloy steels.

Analyses of Rust Samples from the Plates

After seven years' service, samples of the thick layer of rust which soon formed on all four plates and which remained on them throughout, except where removed locally by damage, were analysed ; the results are given in Table VII. The most striking fact is that the sulphur contents are low, 0·17% (as SO_3), and do not differ appreciably with the type of steel.

According to Copson* low-alloy steels depend for their increased resistance to atmospheric corrosion on the formation of an adherent and relatively impermeable layer of rust, which is built up as corrosion

* This result seemed rather surprising and the National Coal Board were, therefore, consulted. Mr. A. M. Wandless, of their Scientific Department, stated that mine waters are almost invariably alkaline, although acid waters sometimes occur at the coal face.

* H. R. Copson, *Proceedings of the American Society for Testing Materials*, 1945, vol. 45, pp. 554–580.

Table VII

ANALYSES* OF RUST SAMPLES TAKEN FROM THE PLATES AFTER SEVEN YEARS' SERVICE

Type of Steel	Specific Gravity	*p*H of Aqueous Extract	H_2O, %	CO_2, %	SiO_2, %	SO_3, %	Total Fe, %	Ferrous Fe, %	Cu, %	Mn, %
Mild steel	4·02	8·7	1·50	0·42	0·09	0·17	64·7	3·55	Not det'd	0·32
Copper steel	4·11	8·2	1·35	0·43	0·10	0·17	64·7	3·83	0·19	0·28
Copper–manganese steel	3·86	9·3	1·77	0·74	0·42	0·17	63·1	2·59	0·32	0·85
Copper–chromium steel	3·94	8·5	1·86	0·48	0·14	0·17	63·6	3·88	0·22	0·58

* All samples contained small quantities of sulphide sulphur ranging up to 0·001% of S and of chloride ranging up to 0·008% of Cl. The chromium content of the rust from the copper–chromium steel was 0·60%

proceeds. The superior protective properties of this rust are associated with the gradual concentration in it of insoluble basic sulphates of the alloying elements, such as copper and chromium, contained in the low-alloy steels. This is demonstrated by the results of tests, reported in Table VIII, on 15 in. × 10 in. specimens cut from the wagon plates under discussion and exposed freely at Sheffield. After six years' exposure the corrosion of the copper steel and of the copper–manganese steel was about 20% less than that of the mild steel; the copper–chromium steel was approximately three times as resistant to corrosion as the latter. The sulphate content of the rust was significantly less for the mild steel, 2·34%, than for the low-alloy steels, 2·53 to 2·78%. The author has found* a similar correlation between resistance to atmospheric corrosion and sulphate content of the rust for a wider range of steels. In corrosive places sheltered from rain, such as railway tunnels, there is, however, little difference between the corrosion rates for ordinary and for low-alloy steels. For example, in the Dove Holes Tunnel, no significant difference was observed after five years between mild steel and two copper steels containing 0·2 and 0·5% of copper respectively. A thick cake of humid rust, which formed on the specimens, contained a high percentage of sulphur, because of the heavy pollution of the tunnel atmosphere by smoke, but this percentage did not differ appreciably for the three steels, the figures observed being 9·4, 9·4, and 9·6% of SO_3.

From both observations, *i.e.*, the low and equal sulphate contents of the coal-wagon rusts and the similarity of the corrosion rates of ordinary and of copper-bearing steels in conditions resulting in the formation of a permanent layer of humid scaly rust, little difference would be expected between the corrosion resistance of the various steels used for the floor plates of these wagons. The results indicate clearly, however, that a marked difference exists in favour of the low-alloy steels; therefore, although the sulphate content of the rust is a valuable index in the case of straightforward open-air exposure, it is not an infallible guide to corrosion resistance.

* J. C. Hudson, *Journal of the Royal Institute of Chemistry*, 1950, vol. 74, p. 298.

Table VIII

RESULTS OF OUTDOOR EXPOSURE TESTS AT SHEFFIELD

Type of Steel	Corrosion Rate,* mils/yr.		Sulphate Content of Rust,† SO_3%
	Over One Year	Over Six Years	
Mild steel	4·2	3·4	2·34
Copper steel	3·4	2·9	2·53
Copper–manganese steel	3·2	2·7	2·78
Copper–chromium steel	3·0	1·3	2·76

* Specimens descaled by sandblasting before exposure

† Samples of adherent rust taken at the end of the test (six years)

PRACTICAL RECOMMENDATIONS

The practical conclusions to be drawn from this work are :

(1) The superstructure of all coal and mineral wagons, *i.e.*, the floor plates, ends, side-sheeting, middle-sheeting, and doors, should be constructed of low-alloy steel. So far, the tests have revealed no significant difference between the three low-alloy steels tested, when used for floor plates. It seems unnecessary, if the choice is governed by corrosion resistance, to use low-alloy steels for the underframe, because these parts are sheltered by the body of the wagon and are usually painted.

(2) Provided that the mechanical properties of the steel remain adequate in the reduced section, the substitution of low-alloy steel for ordinary steel in wagon construction should enable a reduction of at least 20% to be made in the thickness of the plates used, without any decrease in service life, thereby effecting a considerable economy in the dead load.

(3) Steps should be taken to protect the most vulnerable areas of the floor plates, which in this type of wagon are at their bottom outer corners. This might be done by applying a sprayed metal coating to the few square feet concerned.

Acknowledgments

These tests are being made on wagons built by the former London and North Eastern Railway Company (now British Railways, North Eastern Region), and the Atmospheric Corrosion Sub-Committee wish to thank the Appleby-Frodingham Iron and Steel Co., Ltd., Messrs. Dorman Long and Co., Ltd., and British Railways for the provision of facilities and information. Considerable assistance in inspection and testing has been rendered by the Central Research Department of Messrs. Dorman Long and Co., Ltd., at first through the courtesy of Mr. R. A. Hacking and later of Mr. W. W. Stevenson. The Brown-Firth Research Laboratories, Sheffield, and the Bragg Laboratory, Sheffield, have also helped in the analytical work.

The author is indebted to Mr. T. Henry Turner, Superintendent (Metallurgy Division), the Railway Executive, Research Department, and Chairman of the Atmospheric Corrosion Sub-Committee, who suggested the trials, for much helpful advice and support, and to Mr. C. Dinsdale, Regional Works Metallurgist, British Railways, Doncaster, who has collaborated in routine inspections and made the metallurgical examination recorded in Appendix II. The author also acknowledges the assistance received from his colleague Mr. J. F. Stanners in making inspections during the last few years and advice given by Mr. R. Pearcy, of the British Iron and Steel Federation, Statistical Department, regarding the interpretation of the results.

APPENDIX I

Manufacture of the Steels

The mild steel and the copper–chromium steel were produced by one firm and the copper steel and the copper–manganese steel by another.

Mild Steel—The mild steel was made in a 90-ton fixed furnace by the basic open-hearth process, the

Table IX
RESULTS OF METALLURGICAL EXAMINATION OF THE PLATES

Test		Mild Steel	Copper Steel*	Copper–Manganese Steel	Copper–Chromium Steel
Mechanical Tests†	Longitudinal				
	Yield stress, tons/sq. in.	23·3	21·9	23·4	26·5
	Ultimate tensile stress, tons/sq. in.	29·0	31·5	36·4	38·1
	Elongation, %	37	39	35	34
	Reduction in area,%	63	66	65	71
	Transverse				
	Yield stress, tons/sq. in.	22·2	21·5	23·4	27·2
	Ultimate tensile stress, tons/sq. in.	29·1	31·0	36·8	38·1
	Elongation,%	35	37	34	29
	Reduction in area, %	63	54	57	55
Notched-bar impact tests	Longitudinal				
	Actual on 10 × 5 mm. B.S. test piece, ft.-lb.	16·5	17·0	15·9	18·4
	Calculated for 10 × 10 mm. B.S. test piece, ft.-lb.	78	80	75	86
	Transverse				
	Actual on 10 × 5 mm. B.S. test piece, ft.-lb.	12·0	9·7	10·7	9·0
	Calculated for 10 × 10 mm. B.S. test piece, ft.-lb.	57	45	50	43
Brinell hardness	30 kg. load, 1-mm. dia. ball	146	148	172	184
Pendulum hardness	Initial	21	22	24	23
	Induced	26	27	31	28
Grain size	Grains per sq. in. at magnification of 100	64–128	128	128	128
	Inherent ASTM No.	2–3	2–3	3–4	3–4

* Figures relate to a similar cast because no spare material was available from the wagon plates themselves
† Tensile tests were made on round tensometer test pieces with a gauge length of 0·632 in. and a cross-section of $\frac{1}{10}$ sq. in.

charge consisting of 54 tons of hot-mixer metal, 38 tons of scrap, and 9 tons of ore or millscale, partly added as 'feed.' The steel was cast into 10-ton slab ingots; these were cogged to 40 × 5 in. slabs from which the plates were rolled. The finishing rolling temperature was 680–710° C.

Copper Steel—The copper steel was cast from the third of four ladles poured from a 275-ton heat made in a tilting basic open-hearth furnace. The charge consisted of 193 tons of hot-mixer metal, 20 tons of cold pig iron, and 60 tons of heavy scrap; 1 ton of ore was added as feed during the heat. The copper was added to the ladle. The steel was cast into 4½-ton slab ingots, which were cogged and rolled down to ¼-in. plate.

Copper–Manganese Steel—The manufacture of the copper–manganese steel resembled that of the copper steel, except that it was made in a smaller (200-ton) furnace. The charge consisted of 155 tons of hot-mixer metal, 45 tons of heavy scrap, and 1 ton of ore was added as feed during the heat. The copper and manganese additions were made in the ladle.

Copper–Chromium Steel—The copper–chromium steel was made in a 90-ton fixed basic open-hearth furnace, the charge consisting of 47 tons of cold pig iron, 35 tons of heavy scrap, and 6 tons of ore, to which a further 7–8 tons of ore or scale were fed during the heat. The copper and chromium were added to the bath just before tapping; part of the manganese was added to the bath and part to the ladle. The steel was cast into 7-ton ingots. These were cogged into 30 × 5 in. slabs from which the final ¼-in. plates were rolled. The finishing rolling temperature was 680–720° C.

APPENDIX II

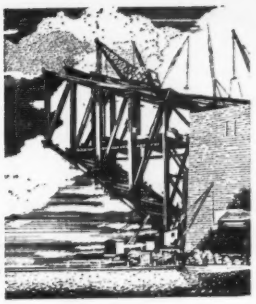
Metallurgical Examination of the Plates

A complete metallurgical examination of the plates was made by the Metallurgical Section of the Chief Chemist's Department, L.N.E.R., in October, 1940. This included determinations of tensile strength, notched-bar impact value, Brinell hardness, pendulum hardness, sulphur print on a section, deep etch on a section, microstructure, and inherent grain size. A summary of the results is given in Table IX.

Chemical analyses of five plates of each type of steel were also made in the L.N.E.R. Darlington Laboratory. Except for a rather wide variation in the carbon content of the mild steel, from 0·15 to 0·23%, the individual results call for no comment and are adequately represented by the average values given in Table I.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



Cooling Beds for Bar Mills

By W. Udall, A.M.I.Mech.E., A.M.I.Prod.E.

SYNOPSIS

The paper reviews briefly the evolution of the merchant bar mill during the last 50 years. The present-day versions of this type of plant have been made possible by the development of the mechanical cooling bed. Several of the earlier and later types of cooling bed and bed mechanisms are described and various factors governing their location and operation are discussed. Theoretical and practical observations relating to thermal treatment and cooling capacity are included, and suggestions are made regarding a possible line of future development.

Introduction

At the turn of this century the merchant bar mill was generally a relatively simple unit comprising little more than a billet reheating furnace, several stands of rolls usually powered from one prime mover, and a cooling floor or static cooling bed. Very few mechanical aids were available or used, and as a result such mills were only suitable for producing a limited range of bar and section weights in short lengths and at low rates of output. The quality and accuracy of the stock produced from these mills, while sufficient for the age they served, must have been low by modern standards.

Industrial development during the last 50 years has created an ever-increasing demand for rolled steel products, and the mass-production industries in particular have had a marked influence on the layout, design, and mechanization of the modern merchant bar mill. The machine tools, jigs, and fixtures, which are a necessary adjunct to mass production, require a consistent and high degree of accuracy and quality, whilst the general appearance and surface finish is often a governing factor in subsequent cold-processing operations and is of great importance to the sales organization. Modern high-output merchant bar mills are highly mechanized and complex units specially arranged and designed to meet these conditions, and are capable of producing a specific range of merchant stock, accurate in section and at high rates of output. These high-output mills have been made possible by the introduction and development of the mechanical cooling bed, the use of which has enabled longer finished lengths to be rolled and consequently much heavier billets to be used.

The obvious benefit derived from the use of heavier billets is the overall improvement in yield, but the less obvious and probably more important benefits, affecting the regularity of the gauge and the quality of the finished product, are derived from the mechanisms necessary for handling these heavier billets. These mechanisms enable the incremental and overall cycle times of all rolling and handling operations to be held reasonably constant, thereby ensuring successive bars being delivered to the cooling bed under more uniform temperature conditions than would have been possible on the older hand-operated mills. This is of considerable importance in plants where a variety of steels are rolled, many of which may require special thermal treatment during the cooling stage.

TYPES OF MERCHANT BAR MILL

The design and layout of an actual bar mill affects the style and type of cooling bed used, but it is not possible, in this paper, to deal adequately with this aspect. However, merchant bar mills may be classified in three main types: (*a*) the fully continuous or straightaway mill, (*b*) the cross-country mill with or without a tandem or continuous roughing train, and (*c*) the semi-continuous mill employing a continuous roughing train, cross-country-cum-looping intermediate or finishing train, and frequently also a continuous finishing train. Examples of these three layouts are illustrated in Fig. 1.

The Fully Continuous Bar Mill

Fully continuous bar mills are designed to roll a restricted range of solid sections from, say, $\frac{3}{8}$ in. minimum to $1\frac{1}{2}$ in. maximum rounds, or equal and heavy flats up to about 5 in. width. They are occasionally used for rolling deformed bars and simple

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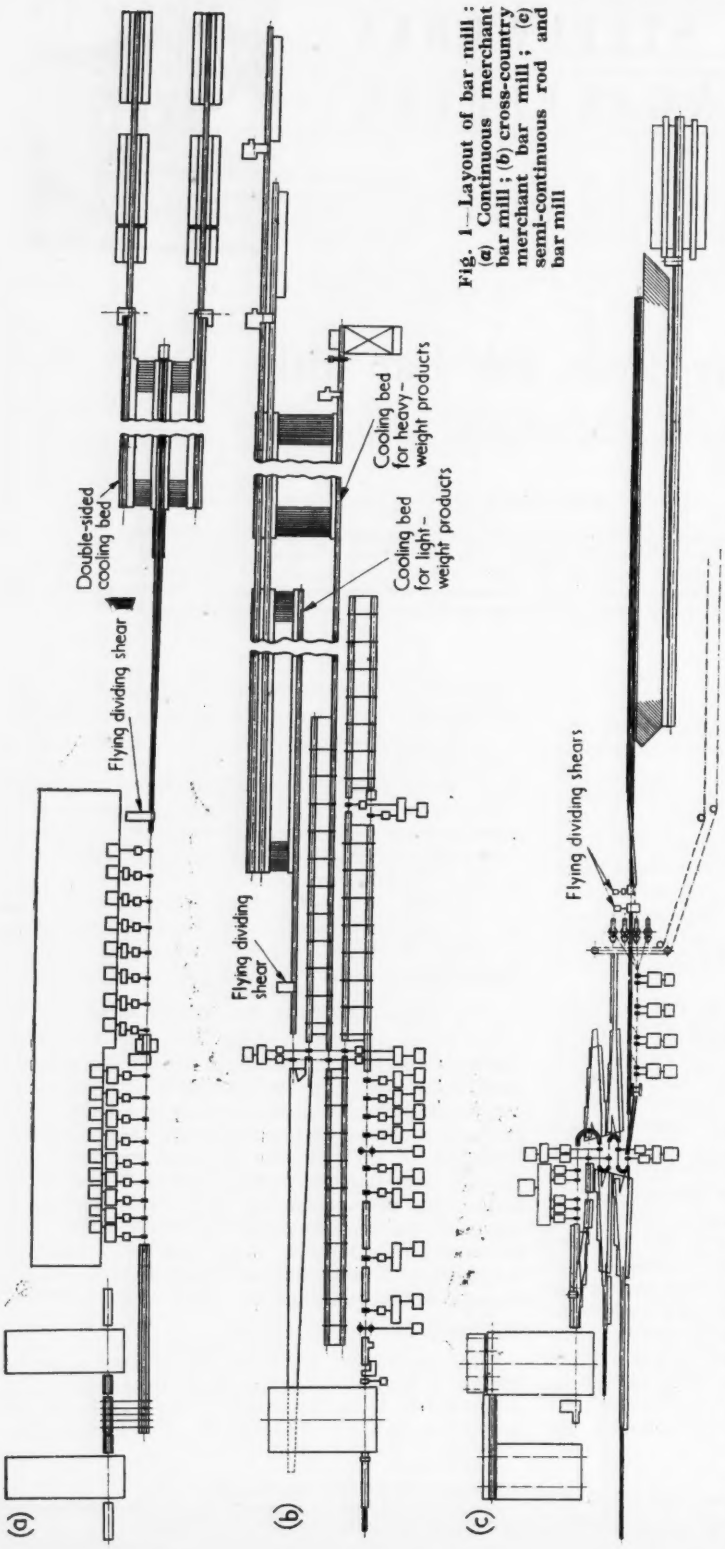


Fig. 1—Layout of bar mill : (a) Continuous merchant bar mill ; (b) cross-country merchant bar mill ; (c) semi-continuous rod and bar mill

sections up to 2½ in. On the type of mill shown in Fig. 1*a*, single-strand rolling is practised, and a standard billet is used for the bulk of the products ; billet weights of 1000–1500 lb. are usual. Finishing speeds up to 2400 ft./min. are employed, and the outputs attained range from 18 tons/hr. on the smaller products to 90 tons/hr. on the best sizes. An average output of 40–45 tons/hr. over a month's rolling is frequently obtained.

Reliable and adequate cooling facilities are required for this type of mill, but equally important, or possibly more so, is the provision of duplicate cold-shearing facilities, if the output of the mill is not to be impaired. Continuous bar mills are usually equipped with double-sided mechanical cooling beds (*see* Fig. 1*a*) varying in design according to the duties required and in length up to a present maximum of 460 ft.

The location of the cooling bed with respect to the mill is governed by the range of sizes rolled, the weight of billet used, and the maximum delivery speed from the finishing stand. When the weight of the billet used is such that all the products can be rolled to bed length or less without subdivision by a flying shear, then the location of the bed is determined by the distance required for bringing a maximum-length bar from full delivery speed to rest. Similarly, if subdivision of the product is necessary and successive cut lengths are delivered to alternate sides of a double mechanical cooling bed, the same factor governs the location of the cooling bed with respect to the flying shear. If, however, all the cut lengths from one billet are delivered on to one side of a double bed, or if only a single-sided bed is available, a further factor, governed by the type of ejector or throw-off gear on the bed run-in table, increases the distance between the shear and the bed. All types of throw-off gear require some time to function ; therefore, each piece must be accelerated after cutting, to create a gap between its tail end and the nose end of the succeeding piece, and the time interval must be at least equal to the time required by the throw-off

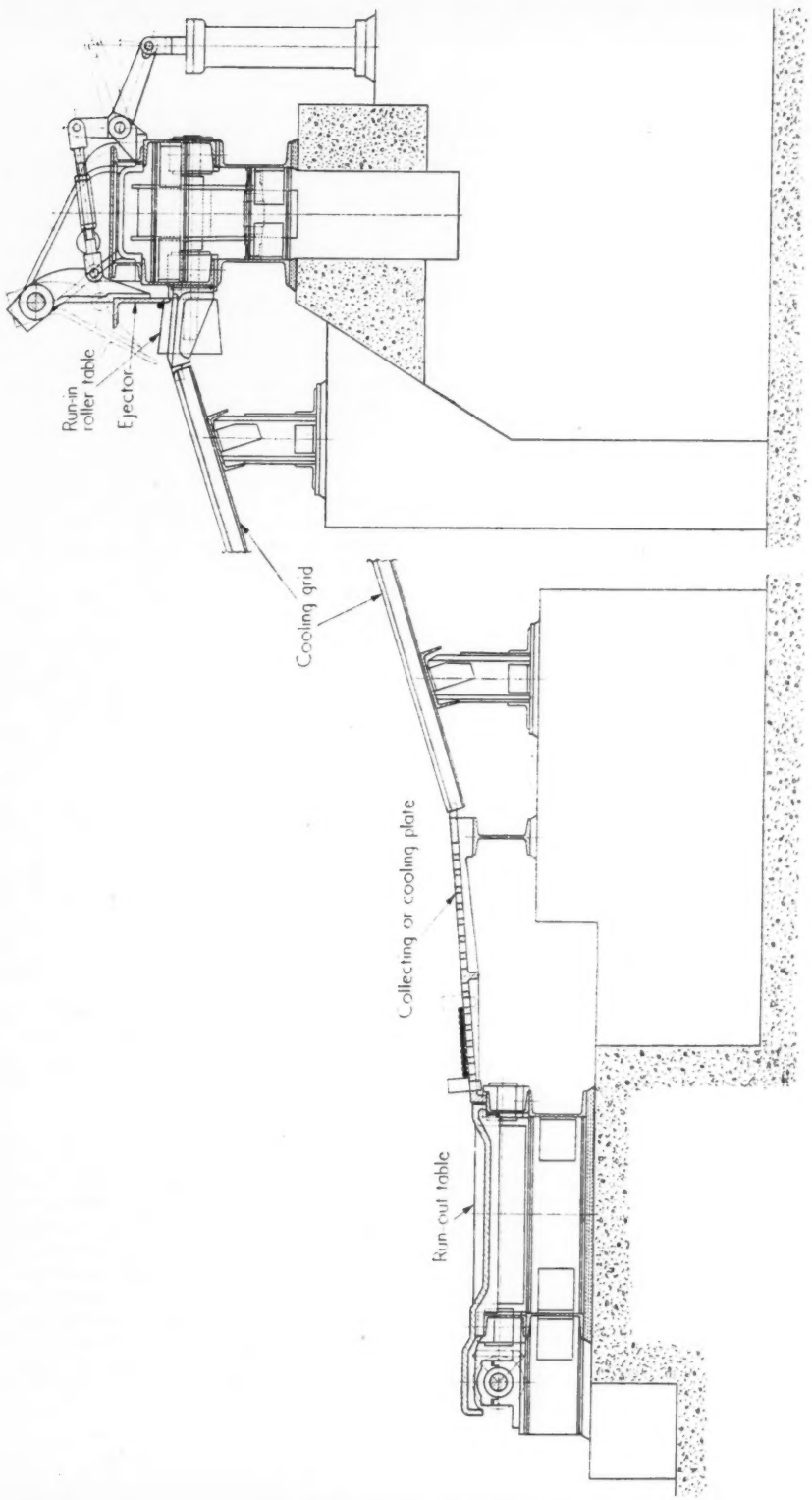


Fig. 2—Cross-section of gravity-type cooling bed

gear to clear the path of the oncoming bar. Thus the space between the flying shear and the bed is increased by the distance required for accelerating the bar plus the increase in the length of slide required to bring the material to rest. With some sizes of bar, this practice necessitates a reduction in the mill delivery speed and therefore a reduction in the possible mill output.

The Cross-Country Merchant Bar Mill

Figure 1*b* illustrates the layout of a cross-country mill employing a tandem-cum-continuous roughing train. Mills of this type are suitable for rolling a wide range of solid and shaped sections at very high rates of output. Depending on the size of rolls used, rounds and equivalent solid shapes from $\frac{3}{4}$ in. to $4\frac{1}{2}$ in. dia. can be rolled, and also a comprehensive range of shaped sections (within the size capacity of the mill). To serve this mill and to cater for the wide range of product weights, two cooling beds are required, one to cater for the long length and lighter range of bar weights and the other to handle the shorter-length heavy bars. As the cooling time required for round bars varies directly as the diameter, the cooling bed for the heavier range of products will of necessity be the wider, to allow a longer cooling time and to cope with the greater rate of output from the mill (*see* Fig. 1*b*). It will be seen from this layout that, even if required, double-sided cooling beds could not be readily accommodated ; to ensure adequate shearing capacity, therefore, duplicate run-out tables and gang shears are used. Furthermore, as both beds cannot be in use at the same time they are arranged to discharge the cooled bars on to common tables.

The location of the cooling beds with respect to the mill is governed by the same factors as those stated for the continuous mill (Fig. 1*a*), but the length of slide necessary to bring the bar to rest is proportionately less, owing to the much lower speeds employed, and the main factor may therefore be the need, or otherwise, for a flying shear to subdivide the very small products.

The Semi-Continuous Merchant Bar Mill

Figure 1*c* illustrates a typical semi-continuous mill for the rolling of a restricted range of solid sections and simple shapes, the smaller sizes of symmetrical solid shapes being produced either in straight lengths or in coiled form. To balance the mill output when rolling the smaller sizes of bar or rod, twin-strand rolling is practised for both coiled and straight products. As a single-sided cooling bed is employed it must be provided with twin run-in tables. In this layout duplicate run-in tables, each with a flying dividing shear, are used ; a third run-in table of more robust design, also with a flying dividing shear, is available for the heavier weight of bar and shaped sections.

The location of the cooling bed with respect to the flying dividing shears is governed by the same factors as those stated for the fully continuous mill ; but as the bulk of the products rolled requires subdivision, and as successive pieces from any one bar are delivered on to one table, the dominant factor is the need to accelerate the bar to create the distance and time intervals for the functioning of the throw-out mechanism.

Only one run-out table and one shear are employed in this layout, as it has been found that one shear can generally cope with the mill output. However, if only one shear is used and the blades are damaged during a run, the bed will rapidly fill up and the mill will have to slow down or stop production until normal operating conditions are restored.

The location of the cold-finishing shear with respect to the bed is an important factor in maintaining throughput and in keeping the bars flowing off the bed at a rate equal to or greater than the mill output. The location of the shear should be such that the oncoming group of bars can be marshalled and deposited on to the shear table before the shearing operation on the preceding group is completed. This factor, although not so important with a double-sided bed, can affect the output if the shears are not properly located with respect to the bed. If for any reason this cannot be done, facilities should be provided on the discharge section of the bed, for marshalling the bars in the requisite groups and for their rapid transference to the shear table.

When a single-sided bed with twin outlets is employed, the location of the shears with respect to the bed is also important. Each shear should be so located that it does not impede the serving of the other. This is usually accomplished by locating the shear serving the run-out table nearest the bed a distance from it equal to at least half the length of the longest bar rolled. The second shear can be located at a similar distance from the bed, or closer if required. An arrangement such as this is shown in Fig. 1*b*, from which it is obvious that both shears can be adequately served. If, for reasons of site restriction, this distance cannot be allowed, a mechanism should be provided to transfer a group of bars from the marshalling section to the second shear table over the top of any bars that may be on the first shear table ; otherwise, the full capacity of the shearing facilities will not be obtained.

Cooling beds and their attendant mechanisms employed on mills such as those shown in Fig. 1 are described later, but first, some of the earlier types of cooling bed, many of which are still in good use today, will be reviewed.

EVOLUTION OF THE COOLING BED

The mechanical cooling bed, in its various forms, may have made the modern merchant bar mill possible, but it cannot be said that the older and simpler form of cooling bed is obsolete or has been completely supplanted by it. Many static and gravity cooling beds still exist and are serving a useful purpose in the industry. They are to be found on hand-operated jobbing mills which are, and probably always will be, required to roll the multitude of small orders for special sections in both mild and alloy steels. As the demand for many of these special sections amounts to only a few tons per year, the cutting and setting of the rolls for a multi-stand high-output mill could not be justified, and the jobbing mill with its simple mechanization is generally the only plant that can be used

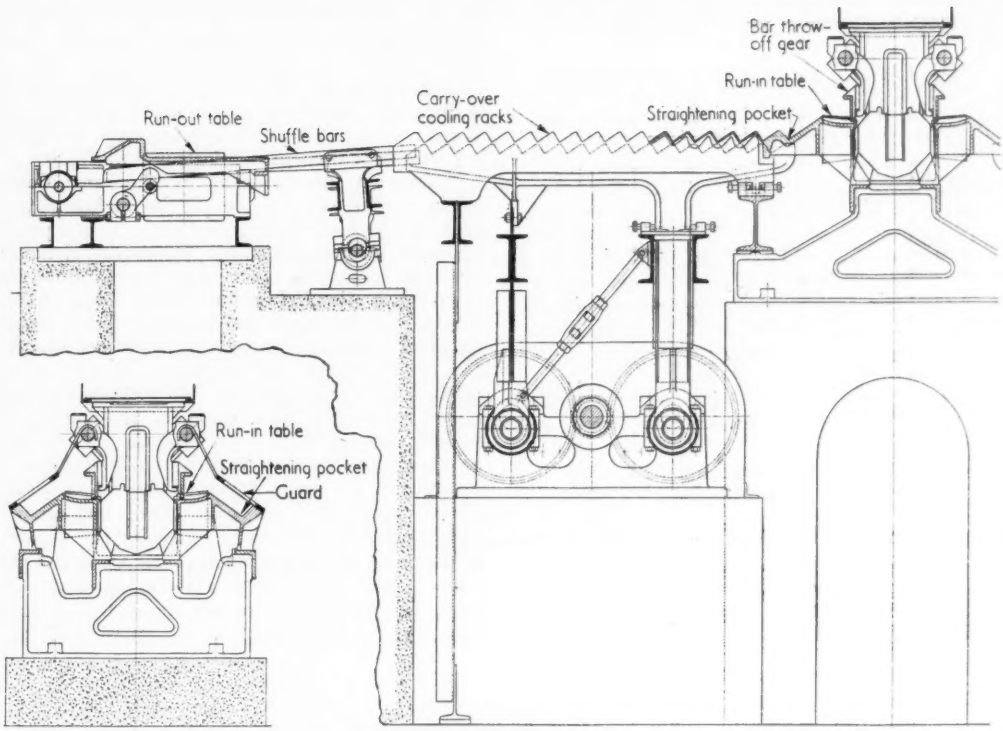


Fig. 3—Half cross-section of carry-over type cooling bed. Inset : cross-section of straightening-pocket extension

economically for this purpose. A typical gravity cooling bed for such duties is illustrated in Fig. 2.

On the older type of bed, steam engines were generally used to drive the roller tables, the run-in table rollers being belt- or rope-driven and the shear-table rollers being coupled to the engine through bevel or mitre gears. In operation, the finished rolled bar is delivered on to the run-in table and is removed therefrom manually or by a simple power-operated ejector, such as that shown in Fig. 2, and allowed to drop on to the cooling grid. If the section being rolled is square, flat, or shaped, the first bar is straightened manually or by a hand-operated stretcher and is deposited a short distance down the cooling grid. Successive bars, after straightening, are laid alongside the first until a pack of the required size is built up. A second pack is then commenced, and as each pack is formed the preceding packs are moved down the grid, ultimately reaching the shear approach table.

When rounds are being rolled, the first bar is allowed to roll down the inclined grid and is brought to rest against a series of pegs in the collecting plate, the rolling action being sufficient to straighten bars of most of the sizes rolled on such mills. Subsequent bars are brought to rest against the preceding bars, and packs are built up as before. Thus, most sections handled on static or gravity beds are slow-cooled in pack formation. This slow rate of cooling, together with the delays that are experienced in manual handling, frequently impaired the output of the mill. To minimize this defect, double-sided gravity beds were sometimes employed, each side of the bed being used to collect and cool alternate packs. Even with this type of bed, the production of merchant stock was restricted, not only in output but also in the size of the section rolled and the length of bar delivered, owing to the lack of mechanical aids on the bed. The length of bar produced rarely exceeded 100 ft.

The introduction of the mechanical cooling bed radically changed the technique of rolling merchant stock ; as a result, a wide variety of medium- and high-output bar mills in all steel-producing countries are now equipped with some form of this bed.

The credit for much of the pioneering and developing of the mechanical cooling bed is due to the Morgan Construction Co., of the United States of America. The first bar mill mechanical cooling bed built by that Company was designed by their engineer Mr. V. E. Edwards, and was of the escapement type employing gravity to advance the bars during cooling.

An early form of this type of bed comprised a run-in table, an escapement or cooling section, and a run-out or shear approach table, and had all the motions powered by steam engines. The run-in table consisted of conical rollers mounted on pivots and linked together so that they could be skewed in unison in either direction. When the bar was advancing from the mill the direction of the skew was such that it would hug the side guards. By changing the direction of the skew the hot bar was thrown off the conical rollers away from the side guards and on to the first notch of the escapement racks.

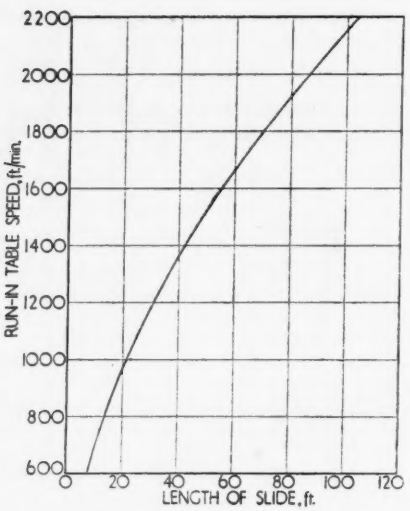


Fig. 4—Effect of run-in table speed on length of slide

These consisted of cast-iron bars set at an incline along the length of the bed and having knobs spaced intermittently, so that by rocking the racks in unison the bar would drop from knob to knob, cooling in the process and remaining straight. Ultimately the bars would reach the run-out table, where they were collected in batches and advanced to the cold bar shear. A drawing of this early type of mechanical cooling bed is not included, but an escapement-type bed embodying later developments is illustrated in Fig. 6.

Subsequent development by the same Company led to the horizontal bed employing rocking saw-tooth racks as the main cooling elements. This is popularly known as the Edward's bed. The cooling elements are vee-shaped in cross-section, each leg of the vee having saw-type teeth pitched alternately along the entire length. These elements are mounted horizontally on pivots and are located across the bed connecting the run-in to the run-out table. They are closely pitched to support the hot bar without sag and are linked together to rock in unison, the amount of the rocking motion being such that the legs of the vee are brought into the vertical position alternately. By rocking the racks together one set of teeth will lift the rolled bar out of one notch and allow it to slide down into the next, maintaining the bar straight in the process, thus employing both power and gravity to traverse the bar across the cooling section of the bed. The run-in table rollers are slightly tapered to cause the hot bar to hug the side guards, and the first

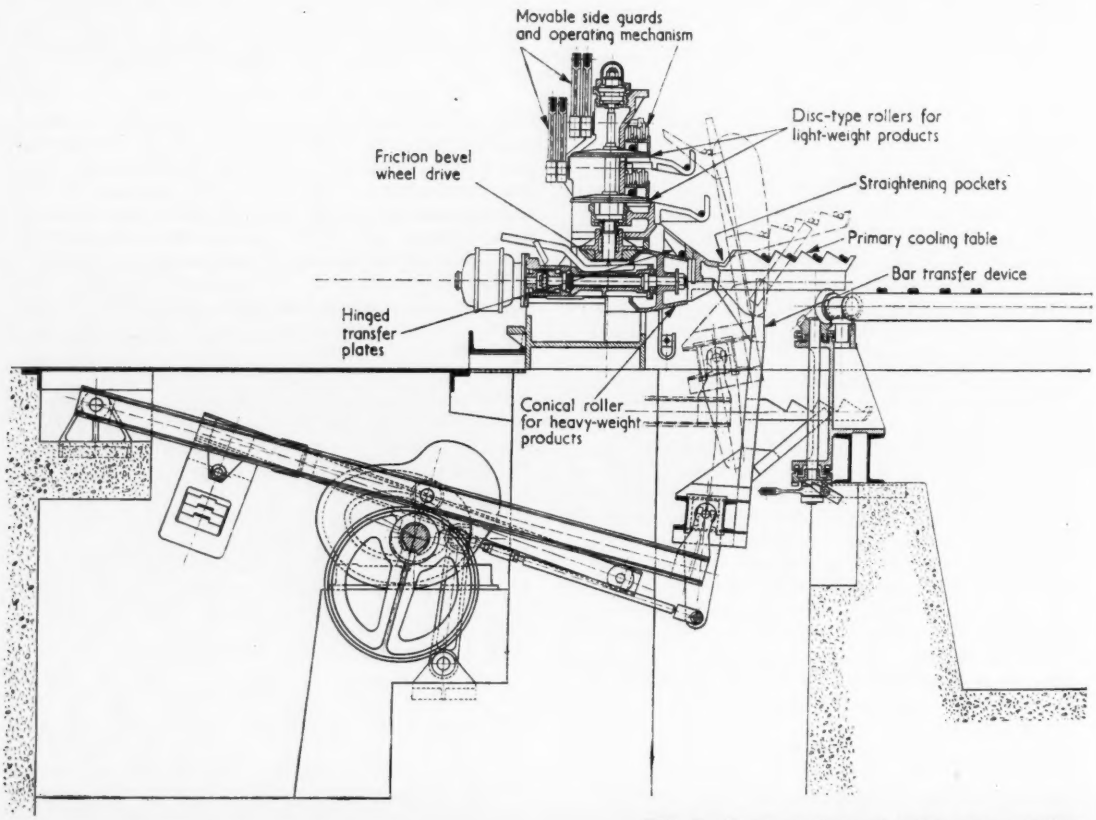


Fig. 5—Cross section of roller-type cooling

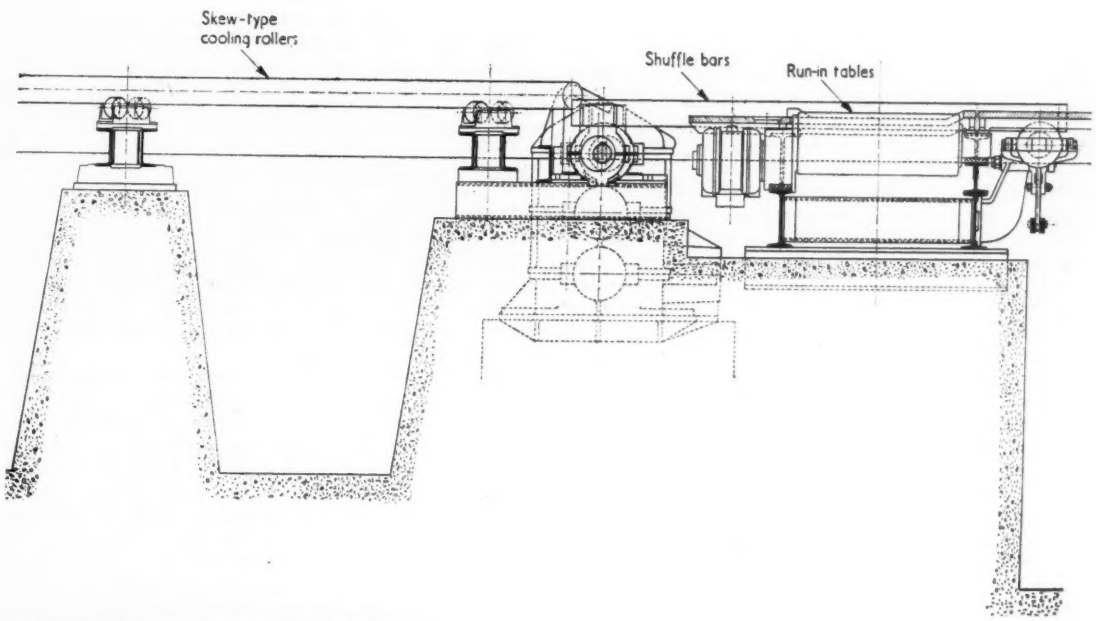
tooth of the saw-tooth cooling elements is used to lift the advancing bar off the rollers and slide it down into the first notch. In the earlier editions of this type of bed the run-in table rollers were belt-driven, and the cooled bars were discharged on to a conventional roller table where they were assembled for shearing in batches.

Many of these beds were built, of the single- and double-sided type, and many improvements were made in detail design and construction, but the next major step forward in cooling-bed design was the introduction of the shuffle bar assembly gear between the cooling racks and the run-out table.

Shuffle Bar Mechanisms

The shuffle bar mechanism consists of a series of flat bars, arranged in pairs, spaced at regular intervals along the entire length of the bed and located between the discharge end of the cooling section of the bed and the run-out table. At the cooling-element end of this mechanism, each bar forming a pair is mounted on an eccentric, adjacent eccentrics being opposed at 180°. The other end of each bar is mounted on a slide or pivot and is arranged to rise and fall a distance sufficient to raise the upper surface of the bars from a position of ambush below the table roller level to a short distance above it. Adjacent to the run-out table, and between it and the cooling elements, are a series of fixed stops spaced along the length of the bed, the height of which is such that the tops are above the shuffle bars in their ambushed position and below them in their elevated position. The rotation of the eccentric shaft in one direction or the other causes any section resting on the shuffle bars to move towards or away from the run-out table.

In operation, each partially cooled bar, as it leaves the cooling elements, rolls or is carried forward by the shuffle bars until arrested by the fixed stops. When there are enough bars to form a batch, or when the preceding batch has left the run-out table, the shuffle bars are lifted and the rolled products are walked forward across the fixed stop and lowered on to the table. If more bars have been collected than are required to form a batch, the shuffle bars are lowered after the requisite number have passed the fixed stops, thereby using these stops as a dividing device and retaining the excess bars on the receiving bed. If more bars are transferred than are required, the rotation of the eccentrics is reversed and the excess quantity of bars is returned. This device, in addition to expediting and facilitating the handling of the rolled products on to the run-in table and thereby using the shearing facilites to the best advantage, also increases the capacity of the bed as a whole, by providing a means whereby a stock of bars can be collected in the event of a hold-up on the shears and



bed for single- or twin-strand rolling

also allowing for further cooling to take place under close-packed conditions. Shuffle bar mechanisms are now standard components on all mechanical cooling beds.

Many other devices were evolved to transfer the bars from the cooling elements to the run-out table, but as all these devices were eventually rendered obsolete by the shuffle bar mechanism they will not be described in detail.

Although this type of bed proved very popular and many single- and double-sided units were built (some of which are still in operation today), its use was generally limited to solid sections and simple shapes. As the need arose for more care and attention to the quality and treatment of the various products and as surface finish began to affect the saleability of the stock, a further step in the evolution of the mechanical cooling bed took place, resulting in the carry-over type of unit illustrated in Fig. 3, now considered by the Morgan Construction Company as their standard and most satisfactory design.

Carry-Over Type Cooling Bed

In this design of bed the use of gravity as an aid to traversing the bars across the cooling racks is completely eliminated. The carry-over elements operate on a similar principle to the shuffle bar mechanism, and lift each bar carefully out of one notch and deposit it in the next without friction, thus avoiding any scratching of the surface. The carry-over unit comprises a series of alternately fixed and floating saw-toothed racks equally and closely pitched along the length of the bed. The fixed racks are adjustably located on the general bed structure at the end adjacent to the run-in table, the other end being supported on a diaphragm to cater for thermal expansion. The floating racks also are adjustably mounted on a structure with similar provision for expansion, the structure in turn being mounted on a series of twin eccentrics and so disposed as to traverse the rolled products in the step-by-step motion already described.

The run-in table comprises a number of specially and compactly designed motors having single- or double-rotor shaft extensions to suit single- or double-sided beds. The run-in table rollers, which are slightly tapered to cause the advancing bar to hug the side guard, are mounted directly on the rotor-shaft extensions. The side guard forms the face of the ejector or bar sweep-off gear, and is mounted on a series of arms carried on a shaft so located above the rollers that by rocking this shaft the side guard moves forward and, contacting the advancing hot bar along its entire length, sweeps it off the roller table, down an incline and into the straightening pocket, in which it slides to rest.

The straightening pocket consists of a series of castings so shaped and located along the full length of the bed as to form an almost continuous anvil against which the bar straightens itself by the force of gravity. The first notch of the floating carry-over racks lifts the bar out of the straightening pocket and deposits it in the first notch of the fixed racks.

On this type of bed the bar retains its full forward speed until it is braked to rest on the surfaces of the straightening pocket. To deliver bars of the maximum possible length on to the bed it is, therefore, necessary to commence the kick-off action before the advancing bar is fully on the bed. To do this, the kick-off mechanism and the straightening pockets are extended at the entry end of the bed towards the mill a distance determined by the length of slide of a bar in coming to rest from the maximim run-in speed. A cross-section of this extension (inset in Fig. 3) shows the guard plates covering the straightening-pocket extensions, for safety.

It is not possible to calculate with absolute accuracy the length of slide necessary to bring a bar to rest, but the curve shown in Fig. 4 gives the probable relationship between bar speed and length of slide, from which an assessment of the required length of kick-off gear and straightening-pocket extension may be made. This curve is computed using a coefficient of friction, between steel at mill delivery temperature and smooth machined cast iron, of 0·2.

Shuffle bar assembly units and run-out tables of conventional design (*see* p. 263) complete the equipment of the cooling bed illustrated in Fig. 3; this forms a very efficient unit of which there are many examples in use today, handling the usual merchant bar mill products in a satisfactory manner.

During this period of development many ingenious devices were evolved and incorporated in cooling-bed mechanisms, in attempts to adapt them to existing and projected new mills operating on very small bar sizes and rolling a multiplicity of strands simultaneously. On the Continent of Europe many varied forms of run-in tables were devised, some of which were arranged to handle up to six strands. These tables must have been relatively costly in capital outlay, difficult to maintain (owing to the necessity for compact design), and uncertain in operation. In addition, the improbability of the bars remaining separate during transfer from the run-in tables to and across the cooling elements must have entailed extra labour and time on the shuffle bars or marshalling table. It is now generally recognized that no more than two bars can be handled simultaneously on a single-sided mechanical bed to retain reasonably efficient and trouble-free operation.

Roller-Type Cooling Bed

The roller-type mechanical cooling bed was developed in Germany, and is much used in Europe. The example illustrated in Fig. 5 is designed to deal with single-strand rolling of medium-weight bar or double-strand rolling of light-weight bar, in conditions similar to those described for the semi-continuous mill shown in Fig. 1*c*. .

The run-in table comprises a number of individually driven and closely pitched roller units, each unit having one slightly tapered roller mounted horizontally and two disc rollers mounted vertically. The disc rollers are coupled to horizontal rollers by friction bevel wheels, which can be disengaged when rolling single strand. The single-strand table is provided with a continuous side guard and a straightening pocket into which the advancing bar is transferred by a series of hinged plates, pneumatically or motor operated through a system of links and levers to cause them to rise and fall in unison. Attached to the

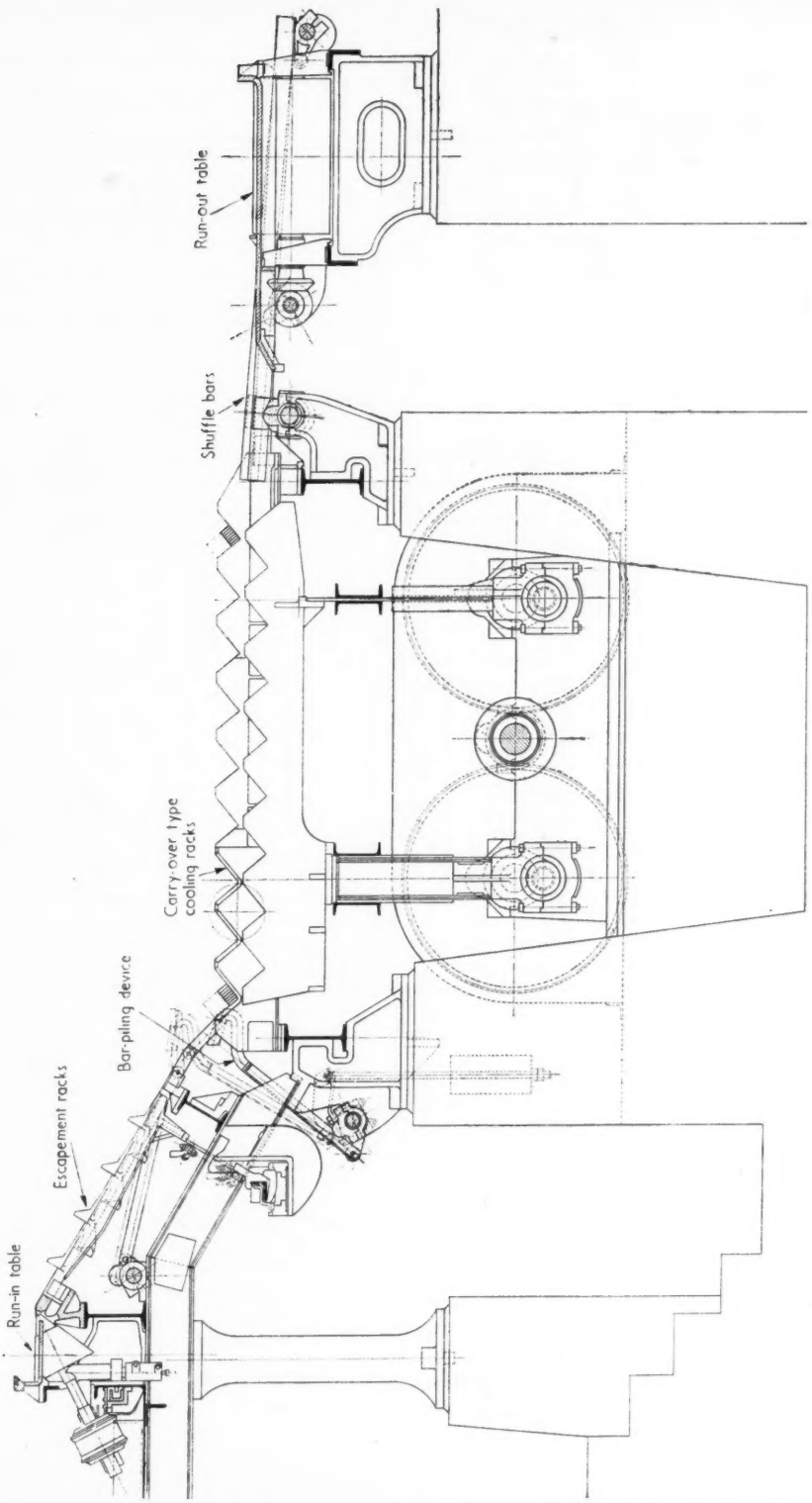


Fig. 6—Cross-section of cooling bed having escapement and carry-over type cooling racks

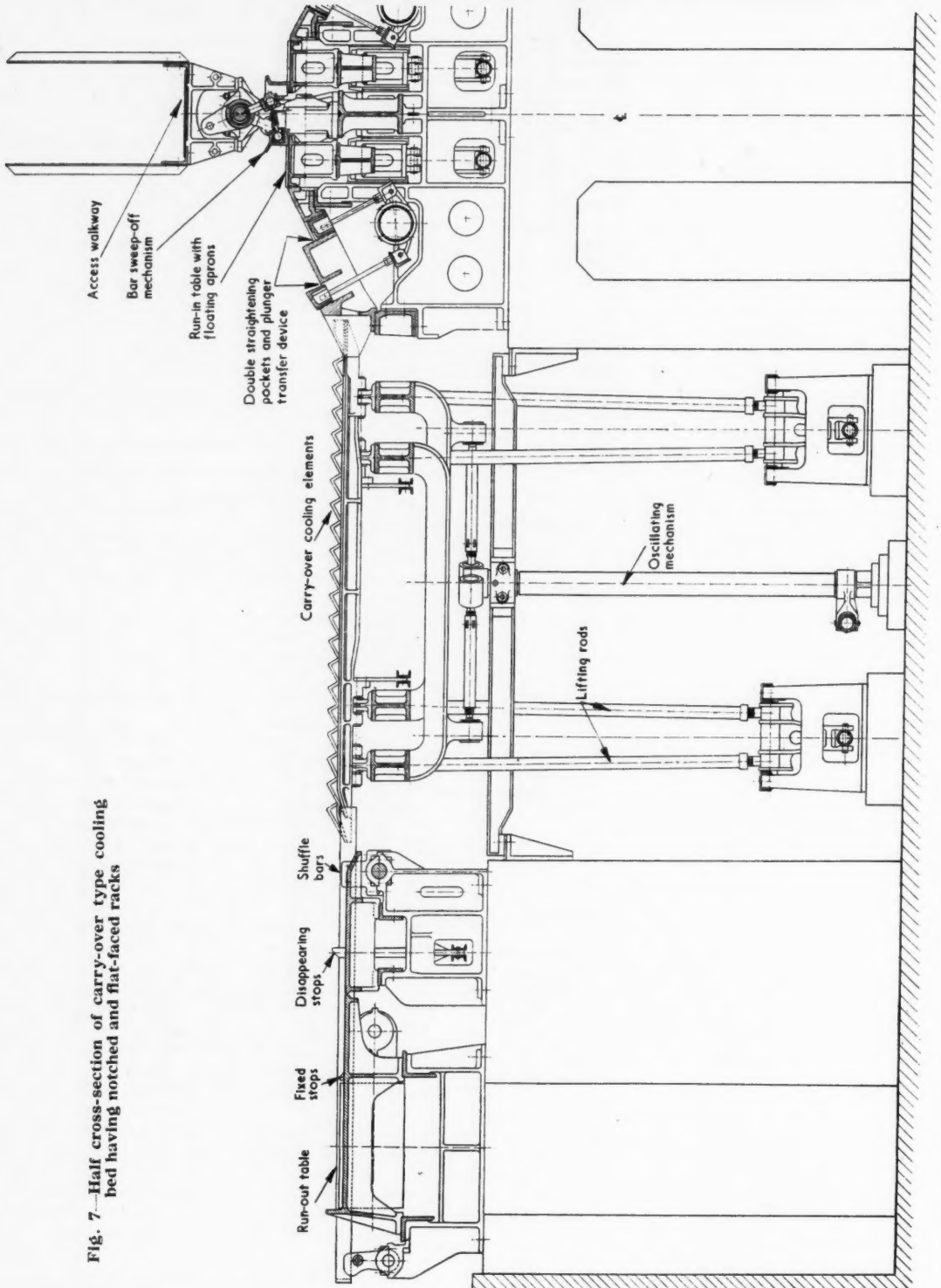


Fig. 7.—Half cross-section of carry-over type cooling bed having notched and flat-faced racks

straightening pocket and forming part of it are a number of saw-toothed racks, which form a primary cooling table. These racks are closely pitched along the full length of the bed, and each rack has four notches into and across which the cooling bars are transferred in step-by-step motion.

The two disc-type roller tables are both provided with two movable side guards, each suspended on a system of levers and pull rods and pneumatically or electrically operated to rise and fall in opposition to each other. A continuous straightening pocket is fitted to each disc roller table ; at the entry end of each table and between it and the flying shear is a mechanically operated switch guide so disposed as to deflect the line of travel of the advancing bar from the path formed between the back plate and the inner side guard to the path formed between the two side guards. The motion of the switch guide is mechanically linked to the side-guard operating mechanism.

In operation, the leading end of the bar advances through the switch guide into the inner path, both side guards being down. When the shear makes a cut, the inner side guard rises and the switch guide moves to a position opposite the outer path. The centrifugal action throws the bar outwards against the outer side guard, and the inner guard lowers. The greater peripheral speed at the outer edge of the disc rollers causes the bar to accelerate, thus creating the necessary gap between the tail and nose ends of the advancing bar (p. 258). As the tail end of the bar passes the switch guide, the outer guard lifts and the switch guide returns to its starting position. Centrifugal force and gravity combined throw the bar into the straightening pocket, in which it slides to rest.

The mechanism for transferring the single or twin bars from the straightening pockets to the primary cooling racks comprises a number of closely pitched forks mounted on a continuous beam structure. This structure is linked to and powered from a system of cams and eccentrics designed to give the forks a path of travel upwards through slots in the straightening pockets and outwards and downward to the starting position, thus lifting the bars out of the pockets and depositing them in the first notch of the primary cooling rack. Attached to these forks are plates which have notches corresponding to those of the primary cooling rack and which, having the same motion, transfer the bars from notch to notch, ultimately depositing them on the roller cooling elements.

The roller cooling elements are a series of smooth round bars closely pitched along the length of the bed and skewed at an angle, usually 45°, to the longitudinal path of travel of the bar. By rotating the skewed rollers any bar resting thereon moves across the bed, at the same time travelling slightly forward or backward depending on whether the angle of skew is backwards or forwards with respect to the path of travel of the material. By driving the skew rollers through a system of bevel wheels from a lineshaft, continuous rotary motion can be obtained if required ; or if a mitre wheel and ratchet drive is employed (*see* Fig. 5) intermittent rotary motion will be obtained. By adjusting the speed of the motor driving a continuously rotating bed, or by varying the stroke of the ratchet mechanism, the pitch of the bars resting on the rollers can be varied, within reasonable limits, to suit the size of the bar and the rate of cooling required.

The shuffle bar assembly unit and the run-out tables forming the remainder of the mechanism of this roller cooling bed are conventional in design, and are generally similar to those units already described.

In theory, if all the skew rollers are set on the same level and at the same angle of skew, any straight bar deposited thereon should remain straight because of the uniform rotation of the rollers. In practice, bars are occasionally bent in transit across the bed, sometimes disturbing and deforming adjacent bars and also necessitating special handling on the shuffle bars and marshalling station. To minimize or obviate this defect, primary cooling tables of varying capacities have been provided in which the bar is held straight in vee-shaped notches. On the primary cooling table the temperature of the smaller sizes of bars falls below the stiffening point, and any subsequent bending that might occur on the skew rollers is not permanent and therefore is not detrimental to the finished product. As, however, the larger sizes of bar deposited on the skew rollers are still above the stiffening temperature, some bars may become bent in transit.

Despite this inherent defect in the roller type of bed, many units have been built and are in use today. In recent years, single- and double-sided skew roller cooling beds have been built for high-production merchant bar mills used on the Continent.

MECHANISMS FOR CONTROLLED COOLING

During this period of development the growth of the merchant bar mill, not only in tonnage output but also in size capacity, rendered it increasingly difficult to justify the use of new plant solely for the production of simple merchant stock in normal steels. Consequently, the need for rolling special steels and a wider range of shaped section became increasingly important.

The roller-type cooling bed required only a minor modification in design to provide the facilities for the close packing of solid shapes on the cooling elements, thereby slowing down the rate of cooling necessary for certain grades of alloy steel. The parallel skew rollers were replaced by others having the shape of a truncated cone, with the small diameter located adjacent to the run-in table discharge mechanism, and with the upper surface horizontal. By regulating the amount of rotation of these rollers, successive bars could be deposited on them in close-packed formation, and the pack thus formed would gradually open out as it traversed the bed, owing to the progressive increase in diameter of the rollers towards the discharge end. As other simple shapes can only be laid edge-to-edge on the skew rollers, this type of bed is not generally suitable for slow cooling or pack annealing, *e.g.*, for spring steel flats.

Escapement and Carry-Over Type Cooling Bed

Figure 6 illustrates a combination of the escapement and carry-over types of bed already described,

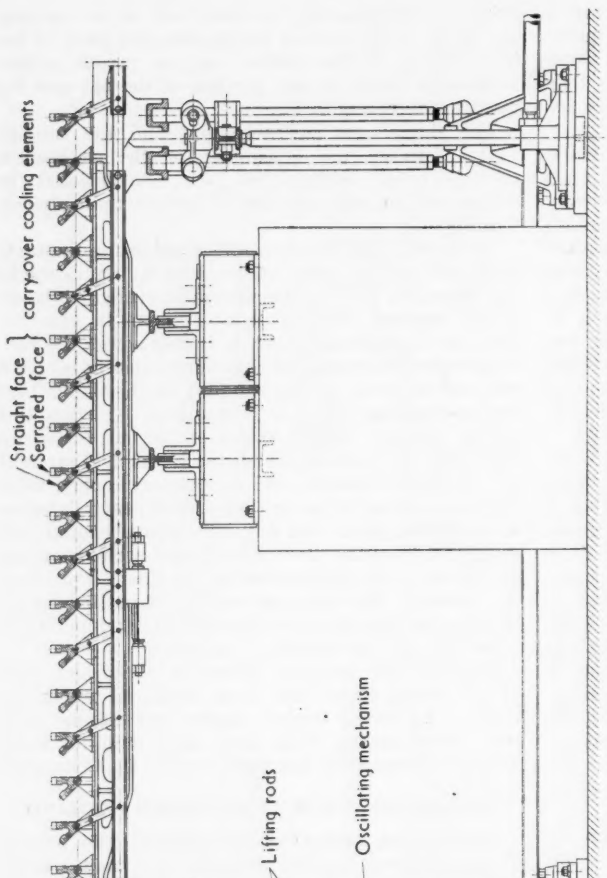


Fig. 8—Various mechanisms for carry-over type cooling bed shown in Fig. 7 : (a) Cross-section of straightening-pocket extension ; (b) longitudinal section of carry-over racks ; (c) continuous pack forming mechanism

which has additional mechanism for forming small packs of flat stock in the notches of the carry-over bars. This additional mechanism consists of a system of links and levers disposed between the lower end of the escapement bars and the first notch of the fixed section of the cooling rack. In rolling the normal run of merchant mill products in steels that do not require any special thermal treatment, successive bars, after leaving the escapement mechanism, slide directly into the first notch of the cooling rack and are conveyed singly to the assembly section of the bed. When flat stock is being rolled in steels requiring slow cooling, this special equipment is elevated to cause successive bars to slide over and come to rest on top of the preceding bars deposited in the first notch, until a pack of the required height is formed. It is then traversed across the bed to the discharge end, where the shape of the flank of the static cooling racks assists in breaking the pack into single flats for assembly on the shuffle bars.

Versatile Carry-Over Type Cooling Bed

The need for cooling facilities to handle the wide variety of solid and shaped sections produced from merchant bar mills, which could be operated to vary the rate and condition of cooling to suit the analysis of steel and shape of section being rolled, led Mr. G. L. Fisk and Mr. E. T. Peterson, both of the U.S.A., to develop a versatile type of mechanical cooling bed. Figures 7–10 illustrate this type of bed and various bed mechanisms, all of which are patented by the parties and companies concerned and are now manufactured by the Birdsboro Steel Foundry and Machine Company of Pennsylvania, U.S.A.

The double-sided cooling bed illustrated in Fig. 7 is designed to accept the general run of merchant bar mill products, and can be used for slow-cooling rounds in continuous pack formation. If required, this type of bed can also be used for handling a wide variety of shaped sections.

The run-in table rollers are slightly tapered and are mounted directly on the motor shafts. The apron plates between the rollers are carried on floating beams, which are raised to lift the advancing hot bar off the rollers and thus slow down, and in some cases stop, the forward travel of the bar before it is swept off into the first straightening pocket. The sweep-off arms are pivoted on the apron plates and in the retracted position form the

run-in table side guard. These sweep arms are connected to a rocking shaft through levers and ball-jointed push rods.

Two straightening pockets, each equipped with plunger-type lifting units actuated from a common rocking shaft, serve to transfer the straightened bar from the first pocket to the second and from thence to the carry-over cooling elements. The two straightening pockets are provided to ensure the bar being perfectly straight before it is deposited on the cooling elements. The surfaces of these pockets, and all other surfaces over which the hot bar slides or is carried (including the run-in table apron plates), are smooth-machined to eliminate any possibility of damaging the surface of the hot material.

The use of lifting aprons to slow down or stop the forward travel of the bar before it is swept-off, materially decreases, and in some cases entirely obviates, the need for the extension of the straightening pockets towards the delivery stand. Figure 8*a* shows the cross-section of the type of straightening pocket extension used when required.

For the handling and transportation of any type or shape of section during the cooling period, the carry-over type cooling elements are each provided with two surfaces, either of which can be used at will according to the form of the section being rolled and the cooling treatment required. The carry-over bars are vee-shaped castings, the top surface of one leg of the vee being provided with accurately machined saw-type teeth and the other with a smooth plain surface. These vee-shaped bars are pivoted and mounted on floating frames, alternate bars being mounted on alternate frames and also being linked together to hold either the saw-toothed face or the plain face uppermost. Each floating frame is mounted on ball-jointed support rods so coupled that alternate frames rise and fall through a predetermined distance in opposition to each other. The alternate frames are also linked through a system of levers and ball-jointed connecting rods, which impart to the frames a rocking motion across the width of the bed. Thus the alternate carry-over bars rise and fall and at the same time move forward and backward in opposition to each other to transport the rolled bars in a step-by-step motion across the bed. A longitudinal section of the carry-over unit is illustrated in Fig. 8*b*. If it is desired to pack successive bars edge-to-edge on the carry-over elements, mechanism can be included by means of which the length of each step of travel across the bed can be readily altered to equal the width of the rolled bar.

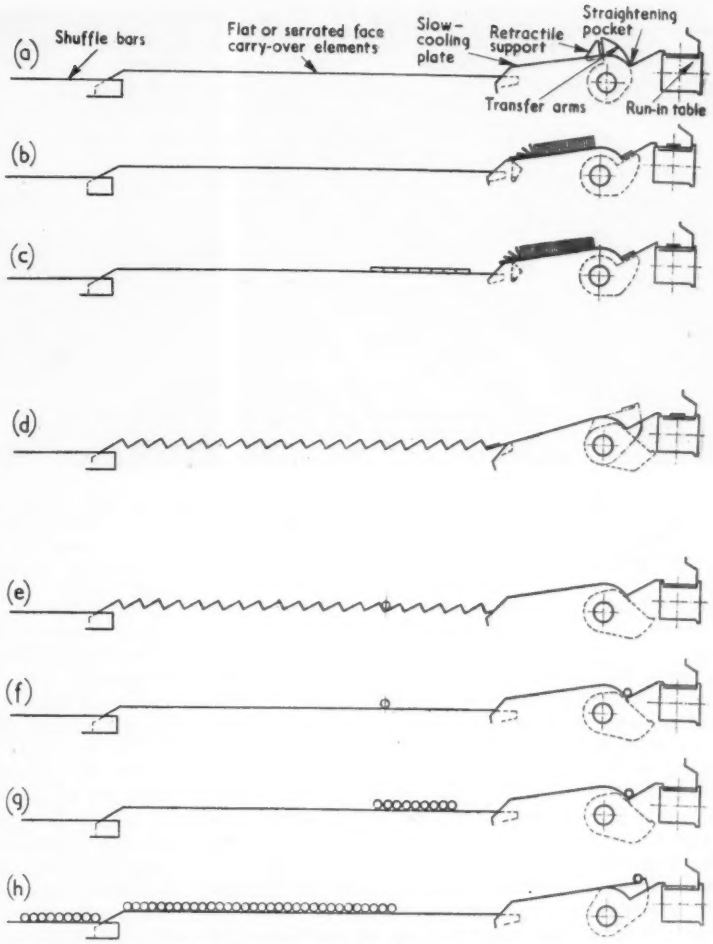


Fig. 9—Diagram of cooling-bed operations

The shuffle bar mechanism and the run-out roller tables forming the remainder of this bed are generally conventional in design, and are similar to those already described. On this section of the bed (*see* Fig. 7) a further refinement is incorporated to facilitate the assembly of the cooled bars for shearing. Power-operated disappearing stops are located about midway between the discharge end of the carry-over bars and the fixed stops adjacent to the run-out rollers. In the bottom position these stops are below the lower level of the shuffle bars, and in the top position the stops will prevent the cooled bars moving forward when the shuffle bars are elevated. By using this mechanism, only the correct number of bars to form a shear batch need be passed forward to the fixed stop.

Slow Cooling of Flats and Squares

The type of cooling bed shown in Fig. 7 is not suitable for edge stacking or packing flat stock for slow cooling. If this duty is required, the double

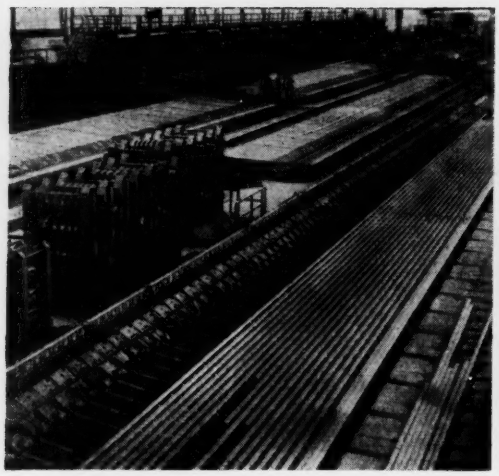


Fig. 10—Single-sided cooling bed incorporating pack-annealing mechanism and two straightening pockets. (By courtesy of the Kaiser Company, Inc., U.S.A.)

Fig. 11—Heavy bar cooling bed. (By courtesy of the United States Steel Corporation)

straightening-pocket unit should be replaced by the mechanism shown in Fig. 8*c*. This equipment consists of a series of specially shaped castings, located between the run-in table and the carry-over cooling elements, the upper surface of which forms a radial and inclined surface over which the rolled products are conveyed. These castings are supported at the run-in table end on a long shaft, which also carries the transfer arms, and at the other end on a system of cranks and connecting rods by means of which the angle of inclination of the surface can be adjusted. The location of this equipment is such that the radial face forms an abutment, against which the hot bars are straightened by gravity and over which all rolled products are conveyed by the transfer arms. One set of transfer arms is shaped and disposed to lift any rolled steel bar out of the straightening pocket to allow it to slide down the incline to the cooling elements. The second set of arms, which are also located on the same shaft but at approximately 180° to the first set, are shaped to lift a flat bar out of the pocket and stand it on edge against retractile supports or against the preceding bar. The retractile supports operate in slots in the castings and can be drawn into ambush when not required.

Figure 8*c* also illustrates an alternative form of apron-lifting mechanism and bar sweep-off gear. This gear comprises a number of crank-operated arms which, when in the dormant position, are in ambush below the surface of the table. In operation the arms rise and sweep forward across the table, thus transferring the advancing or stationary bar into the straightening pocket and thereafter returning to the starting position below the level of any bar that may be advancing on the run-in table. The delay between successive bars is thus reduced to a minimum.

The method of operating this equipment is illustrated diagrammatically in Fig. 9. When flat stock is being rolled and slow cooling is required, the retractile supports are brought forward to the position shown in Fig. 9*a*, and the first flat is transferred from the straightening pocket by the specially shaped lifting arms and is stood on edge against these supports. Successive bars are transferred in the same way, gradually building up a pack and causing the supports to retract and ultimately to withdraw into ambush below the surface of the table (Fig. 9*b*). When this occurs the leading flats in the pack collapse, and the addition of further flats gradually pushes these on to the flat-faced carry-over elements (Fig. 9*c*). With the exception of the first and last pieces rolled, each of which has one face exposed to the atmosphere, all the flats in any one rolling programme receive uniform thermal treatment, thus rendering them suitable for subsequent mass-production processes.

If the flat stock rolled is in a quality of steel that does not require slow cooling, then, by increasing the inclination of the surface of the tables and by using the other transfer arms provided, each flat is lifted out of the straightening pocket and allowed to slide directly into the first notch of the carry-over elements (Fig. 9*d*). Thereafter, they are conveyed in step-by-step motion to the shuffle bar assembly unit.

Slow Cooling of Round Bars

If round bars are being rolled and if controlled cooling is required (as with spring steel and some screw-cutting steels), the bed is first set up as shown in Fig. 9*e*. The first bar rolled is deposited in the first notch of the saw-toothed cooling racks, and is transferred as rapidly as possible to the position shown. The cooling racks are then rocked over to bring the flat face uppermost (Fig. 9*f*), and subsequent bars are allowed to roll down the incline and across the cooling racks until brought to rest by the preceding bars. When a narrow pack is built up (Fig. 9*g*) it is walked over a distance equal to its width. The repetition of this process ultimately builds up a continuous pack, as shown in Fig. 9*h*.

This process can be accomplished equally efficiently

with the equipment shown in Fig. 7, the adjustable inclined table being replaced by the double straightening-pocket equipment. If square bars requiring slow cooling are to be rolled, they can be handled and cooled in the same manner as that described for flat stock.

Cooling of Miscellaneous Shaped Sections

If the sections to be rolled are prone to cambering during cooling, and if these sections are of such a shape or type that they cannot be carried and held straight in the notches of the saw-toothed racks, then the sections can be packed edge to edge on the flat-faced bars. By incorporating adustable levers in the cooling-rack operating mechanism, the length of each step of the carry-over movement can be made equal to the width of the section rolled, over any reasonable range of widths.

The cooling bed shown in Fig. 10 is a single-sided unit generally similar in design to that shown in Fig. 7 but incorporating a different type of pack-annealing mechanism to that shown in Fig. 8*c*. On this bed two straightening pockets are used, and after leaving the second pocket the general run of merchant bar products requiring no special thermal treatment are transferred across an inclined grid to the carry-over racks. The transferring action is accomplished or assisted by pushers operating in slots below the straightening-pocket level. When pack annealing or slow cooling of flats or squares is required, this equipment functions in a manner similar to that described on p. 270, with the pushers replacing the specially shaped lifting arms.

Cooling Bed for Heavy Products

To meet the greater cooling time required for the heavier range of merchant mill products, such as would be obtained from the cross-ccuntry type of mill illustrated in Fig. 1*b*, a cooling bed of shorter length, greater width, and more robust construction than any previously described or illustrated, will be required. The cross-section of such a cooling bed is shown in Fig. 12.

The run-in table is of conventional design and comprises the requisite number of plain cylindrical and equally pitched rollers, group-driven from motors through mitre or bevel gears, the motors being arranged for start-and-stop operation. These roller units are provided with fixed apron plates which extend to span the space between the run-in table and the carry-over cooling elements, thus forming a continuous primary cooling plate. The hot bar transfer or kick-off gear consists of sliding carriages equally spaced along the length of the run-in table and disposed between the rollers and below the apron plate level. Each carriage is fitted with two disappearing dogs linked together to operate in unison and coupled to rocking levers through connecting rods. In operation, the movement of the rocking lever causes the dogs first to rise from the ambushed position and then to transfer the bar from the roller table to the primary cooling plate. On the return stroke, the dogs first drop into ambush before the carriage retracts to the starting position. The next forward stroke to transfer a subsequent bar also moves the first bar from the cooling plate to the first notch of the carry-over cooling racks.

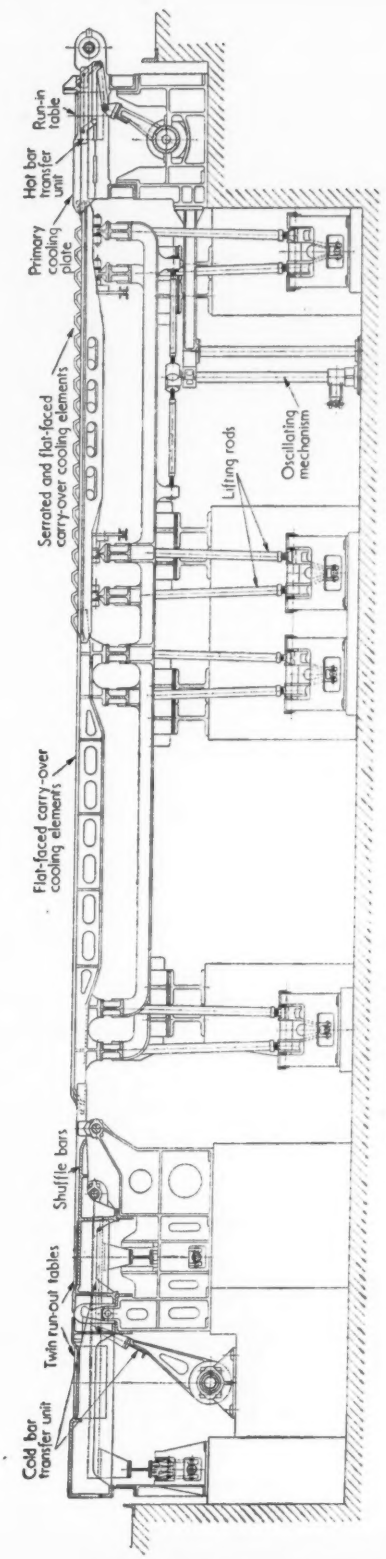


Fig. 12—Cross-section of heavy bar cooling bed with twin run-out tables

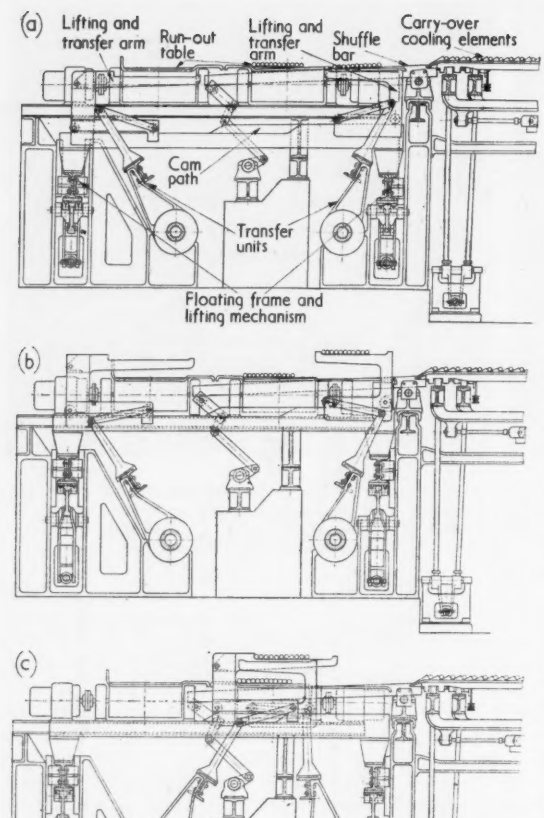


Fig. 13—Bar transfer device

The carry-over cooling racks are generally similar in design to those shown in Fig. 7, except that they are of heavier construction. Two sets of cooling racks are provided, which are linked together to operate in unison. The racks of the set nearest to the primary cooling plate have both notched and flat faces, and are operated as described earlier. The second carry-over unit is provided with flat-faced racks only, unless rounds are to be handled, in which case four or more pairs of racks with either flat or notched faces, depending on the length and duties of the bed, may be incorporated. Straight rounds would roll, owing to the movement of the racks, and these notched bars are necessary to keep them in alignment. The cooled bars are transferred from the flat-faced cooling racks to the run-out roller table by shuffle bar mechanism.

Figure 11 is a photograph of the heavy type of cooling bed illustrated in Fig. 12 ; the general form of the notch bar and flat-faced cooling elements can be seen. When this photograph was taken the unit was operating on short-length squares ; it will be noted that two rows of squares are crossing the bed simultaneously, thus employing the cooling area to the best advantage.

A cooling bed of this type is of necessity a single-sided unit, and twin run-out tables are required to provide adequate shearing facilities. If the shear serving the table nearest the carry-over elements can be located at a distance from the bed equal to at least half the length of the longest bar rolled, a transfer device similar to that shown in Fig. 12 can be used to convey the cooled bars to the second shear table.

Cold Bar Transfer Mechanisms

These devices consist of a series of sliding transfer bars carried in guide troughs equally pitched along the length of the bed. The guide troughs, which span both shear tables, are supported on a floating structure which can rise and fall, being power-operated through bell crank levers and pull rods. In the lower position the transfer bars are below the apron plate level, and in the transferring position they are raised above the level of the table rollers. These transfer bars are linked by connecting rods to rocking levers.

In operation, the cooled bars are assembled and transferred by the shuffle bars to the first shear table ; the floating structure is then raised, thus lifting the bars clear of the rollers. In this position the bars are moved across to the second table by the transfer carriages, which, after lowering, return to the starting position.

If, due to the layout of the mill or to restrictions imposed by the site, it is only possible to locate the two shears in close proximity to the cooling bed, then the bar transfer device illustrated in Fig. 13 can be used. This equipment, other than the twin run-out tables, comprises two sets of power-operated lifting and transferring arms equally and closely pitched along the length of the bed. One set of lifting arms, when in the ambushed and retracted position, is located immediately below the level of the cooled bars on the shuffle bar assembly station. The other set of lifting arms, when also in the ambushed and retracted position, is below the level of the aprons on

the outer run-out table. The lifting arms are shaped as shown in Fig. 13*a* ; the upper portion of the arms supports the cooled bars during the transferring operation, and the lower portion is fitted with rollers which ride on guide bars. The guide bars are mounted on a floating structure, which can be caused to rise and fall by means of a system of levers and connecting rods. The portion of the guide bars on which the inner set of transfer arms travels is level, and the portion on which the outer arms move is partly level and partly cam-shaped. The movement of the transfer arms towards and away from each other is accomplished by two separate systems of rocking levers and connecting rods.

When it is desired to transfer cooled bars from the shuffle-bar assembly station to the outer run-out table, over bars already on the inner run-out table (Fig. 13*a*), the two sets of transfer arms are first raised to the position shown in Fig. 13*b*. The inner set of arms is then stroked forward to the position in which the cooled bars are mainly supported directly over the inner run-out table (Fig. 13*c*). The outer arms, in moving forward, first pass under these bars and then, by means of the cam-shaped guide tracks, rise and lift the rolled bars still further. The inner transfers retract, and immediately afterwards the outer arms also retract to the positions shown in Fig. 13*d*. The lowering of the guide tracks completes the cycle of operations, leaving the cooled bars on the run-out table (Fig. 13*e*). At no time during this transfer operation have the bars on the inner table been disturbed or the shearing operation on them interrupted.

DELIVERY OF ROLLED BAR

A prime necessity for the successful operation of a mechanical cooling bed is that the rolled bar should be presented to it as straight as possible, and also that the path of travel of the bar from the delivery stand to the bed should be as nearly linear as circumstances will allow. Careful attention to the pass design, the setting of the mill rolls, and the type and fixing of the stand furniture, will ensure the majority of sections rolled being delivered straight, and it is therefore essential that equal care and attention should be given not only to the operation but also to the design of any ancillary equipment between the mill and the bed.

In plants where a single-sided bed only is used, the mill run-out and cooling bed run-in tables will normally form a straight path for the bar. If the bar sizes produced are within the length capacity of the bed, so that all can be rolled without sub-division, it will be sufficient to ensure that the table rollers are pitched to carry the lightest bar without undue sag, and that the rollers are powered to match the full range of bar delivery speeds. To assist in maintaining straightness it is common practice to induce a slight tension in the bar, by setting the peripheral speed of the table rollers slightly higher than the mill delivery speed.

When a double-sided bed is used, the advancing bar must of necessity be deflected from a straight path when traversing the **Y**-shaped tables. The amount of this deflection should be reduced to a minimum by locating the bed at an adequate distance from the mill, and the design of the mechanical switch necessary for deflecting the bar to either side of the bed should be such that it will not distort or mark the advancing bar. The table rollers should be slightly tapered and/or skewed, to keep the advancing bar against the side guard and so minimize the danger of it leaving the run-in table prematurely. This is particularly important when flat stock or substantially flat shaped products form part of the rolling programme.

The shearing of hot metal is always accompanied by some distortion, and the design of a flying dividing shear for operation in conjunction with a high-speed bar mill and a mechanical cooling bed therefore requires careful consideration. The shape, disposition, path of travel, and speed, of the shear blades should be such that any distortion of the bar will be confined, as far as possible, to the tail end rather than to the leading end of the cut pieces. Any bending or knuckling of the leading end of a bar will increase the possibility of it leaving the run-in table prematurely.

ELECTRICAL CONTROLS

As the speed of the run-in table must be related to the speed of the mill, the motors driving the table rollers are electrically linked to the delivery-stand motor. For a cooling bed such as that illustrated in Fig. 7, operating in conjunction with a fully continuous mill, the table-roller motors will be A.C. squirrel cage units of 0·2–1·0 h.p., and will have a speed range of about 212–1060 r.p.m. to give the rollers a peripheral speed of 500–2500 ft./min. These motors receive their power from a variable-frequency generator set. The motor driving the generator set is coupled to the D.C. supply feeding the delivery-stand motor, and therefore any variation in the speed of the mill during rolling will result in a corresponding variation in the speed of the run-in tables.

The various mechanisms employed in mechanical cooling beds usually require rapid acceleration and retardation, and D.C. mill-type motors are generally used, because of their high torque characteristics and low armature inertia. For automatic operation the motors powering the various units from the bar kick-off to the carry-over cooling racks are usually electrically interlocked by limit switches, which can be short-circuited as required when manual control from the cooling-bed pulpit is to be used.

The initiation of the cycle of automatic operations usually emanates from the motion of the advancing bar by the use of flag switches, contact rollers, or light- or heat-sensitive cells, but if necessary the action of a preceding machine such as a flying dividing shear, or the load imposed on the mill delivery stand, can be used for this purpose.

Flag switches, suitably disposed on the run-in table, can be used with success when the section of the stock rolled is relatively heavy and the delivery speed low. However, flag switches can cause the premature discharge of a bar from the run-in table, and therefore are not generally used when light-weight stock and high-speed finishing dominate the programme. Contact rollers have been used with considerable success,

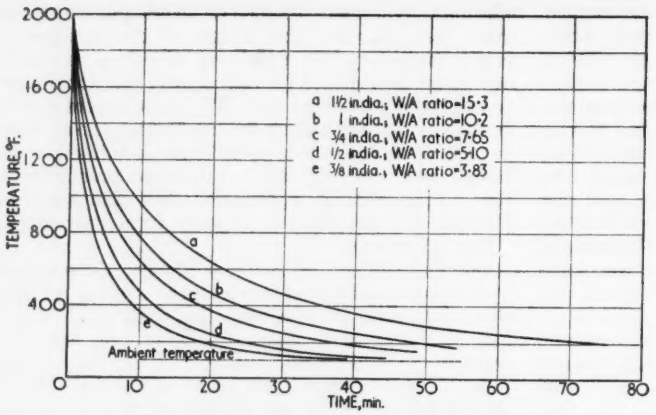


Fig. 14—Effect of size on rate of cooling

but in this country the regulations governing the use of electricity, particularly with regard to the insulation of electrical equipment from earth, present the plant designers with problems of cost and maintenance that cannot be readily solved. Light-sensitive cells can be and have been used for this purpose, but these units, unless frequently and carefully maintained free from dust and atmospheric contamination of the lenses, can rapidly lose their efficiency and become unreliable in operation. When the product rolled does not require subdividing, the load imposed on the main mill motor by the bar entering the delivery stand rolls can be used to start the cooling-bed operation, but if subdividing is necessary then the action of the flying shear can be employed for the same purpose.

Whatever form of signalling is adopted, the wide range of delivery speeds available in modern merchant bar mills necessitates an accurate and adjustable time delay switch in the circuit, to ensure successive bars being discharged at the same position on the bed. It is preferable to locate this switch in the cooling-bed pulpit control desk, to enable the operator to make any adjustments rendered necessary by a change in mill speed. The operator may then cause any bar to be discharged on to the cooling elements a few feet ahead of its correct position, to facilitate the cutting of sample or test pieces.

RATE OF COOLING

If all conditions pertaining to the cooling of rolled steel products could be firmly established it would be possible to calculate accurately the rate of heat loss for any shape or weight of section. Factors affecting the rate of heat loss are: shape, cross-sectional area, surface condition, and composition of the material to be cooled; the design of the equipment used to transport and support it during cooling; the proximity of other heated bodies; and the general surrounding conditions. These factors vary from plant to plant and frequently vary from hour to hour in any one plant, and an accurate general computation therefore cannot be made.

By making assumptions, a general estimate of the rate of cooling (sufficiently accurate for practical purposes) can be made, provided that the calculations based on each group of assumptions are limited to a restricted range of section shapes, sizes, and weights. An example of such calculations, based on hypothetical conditions, is depicted graphically in Fig. 14, for a range of round bar from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. dia. inclusive. The assumptions on which these calculations were based do not relate to any particular plant, but the curves obtained approximate, over the higher portion of the temperature range, to some of the experimental results illustrated in Fig. 15. These theoretical curves show that, all other conditions being equal, the time taken for cooling a round bar varies directly as the diameter, over the range of sizes considered.

The cooling curves illustrated in Fig. 14 are based on the assumptions that no form of forced convection is used on the cooling bed and that the heat losses due to conduction are sufficiently small to be ignored. The remaining factors, *i.e.*, radiation and natural convection, affecting the dissipation of heat are related in Fig. 16, which shows that, over the higher range of temperatures, the heat loss due to radiation far outweighs that due to natural convection. At the lower end of the temperature range the losses due to natural convection become increasingly important, but, as rolled bars are generally discharged on to the shuffle bars or run-out table at temperatures at or above 450° F., this does not have a marked effect on the overall cooling capacity of the bed.

The time for a particular section to cool through a known temperature range may be calculated from Fig. 17. First, establish the W/A ratio of the section:

$$\frac{W}{A} = \frac{\text{Weight of section, lb. per ft. length}}{\text{Surface area, sq. ft. per ft. length}}.$$

From Fig. 17 read off the values of the horizontal ordinates at the higher and lower temperatures under consideration, and subtract the lower from the higher value. Multiply the figure thus obtained by W/A, and the result will be the time required (in minutes).

Example—Consider the cooling of a $1\frac{1}{2}$-in. dia. bar from 1600° to 400° F.:

Weight of 12-in. length of $1\frac{1}{2}$-in. dia. steel bar = 6·008 lb.

Surface area of this section = 0·393 sq. ft.

$$\therefore \quad \frac{W}{A} = \frac{6{\cdot}008}{0{\cdot}393} \simeq 15{\cdot}3.$$

From Fig 17:

400° F. ≡ 2·373 on the horizontal ordinate
1600° F. ≡ 0·125 „ „ „ „
Difference ≃ 2·25

∴ Cooling time = 15·3 × 2·25 = 34·4 min.

Figure 17 can also be used to estimate the finishing temperature of a section when the run-in temperature and the time of duration on the bed are known. Furthermore, any other simple section (such as a square, rectangle, or angle) can, by use of this graph, be compared with the equivalent round having the same W/A ratio and consequently the same rate of cooling.

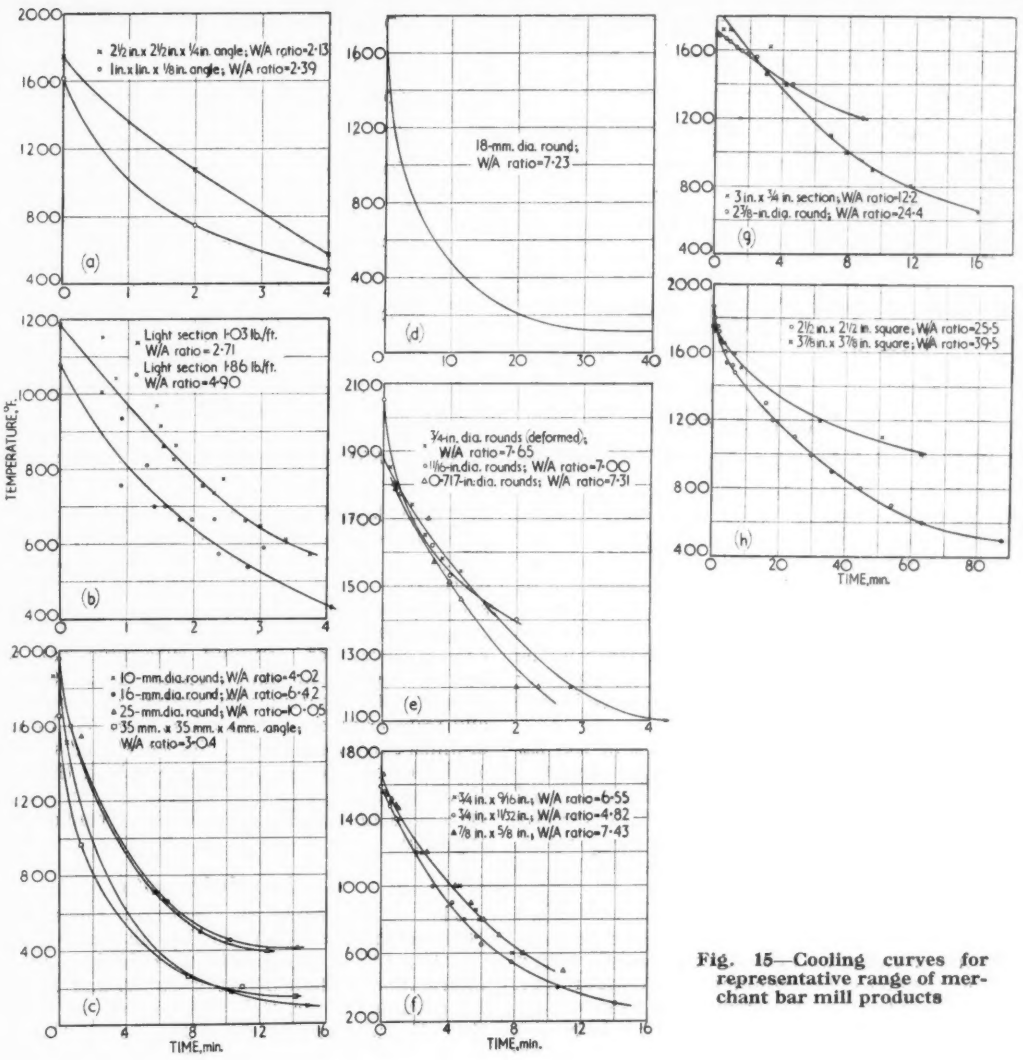

× 2½ in. x 2½ in. x ¼ in. angle; W/A ratio=2·13
○ 1 in. x 1 in. x ⅛ in. angle; W/A ratio=2·39
(a)
Light section 1·03 lb./ft. W/A ratio = 2·71
Light section 1·86 lb./ft. W/A ratio=4·90
(b)
10-mm. dia. round; W/A ratio=4·02
16-mm. dia. round; W/A ratio=6·42
25-mm. dia. round; W/A ratio=10·05
35 mm. x 35 mm. x 4 mm. angle; W/A ratio=3·04
(c)
18-mm. dia. round; W/A ratio=7·23
(d)
¾ in. dia. rounds (deformed); W/A ratio=7·65
1 1/16 in. dia. rounds; W/A ratio=7·00
0·717 in. dia. rounds; W/A ratio=7·31
(e)
¾ in. x 9/16 in.; W/A ratio=6·55
¾ in. x 11/32 in.; W/A ratio=4·82
⅞ in. x ⅝ in.; W/A ratio=7·43
(f)
× 3 in. x ¾ in. section; W/A ratio=12·2
○ 2⅜ in. dia. round; W/A ratio=24·4
(g)
○ 2½ in. x 2½ in. square; W/A ratio=25·5
× 3⅜ in. x 3⅜ in. square; W/A ratio=39·5
(h)
TEMPERATURE, °F.
TIME, min.

Fig. 15—Cooling curves for representative range of merchant bar mill products

It can be shown mathematically that the equivalent diameter d for any simple shape, such as a square or rectangle, is given by :

$$d = \frac{4 \times \text{Cross-sectional area}}{\text{Periphery}}.$$

The cooling curves plotted in Fig. 15 cover a representative range of merchant bar mill products, from very light shaped sections to medium-sized rounds and squares. The observations from which these curves were compiled were generally made under normal operating conditions. Of the 19 bars or sections studied, three were allowed to cool to a temperature approaching the ambient, and 11 to temperatures between 650° F. and 300° F. at the shuffle bar assembly station or run-out table ; observations on the remaining five bars were discontinued while the bars were still at elevated temperatures.

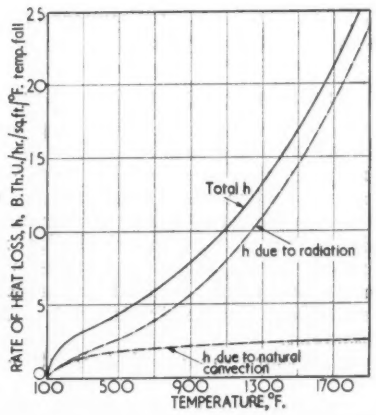


Fig. 16—Heat loss due to radiation and convection

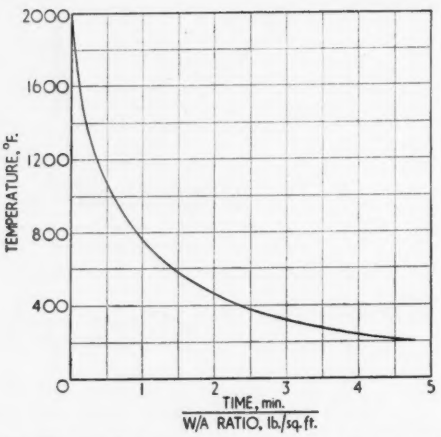


Fig. 17—Theoretical curve for purposes of comparison

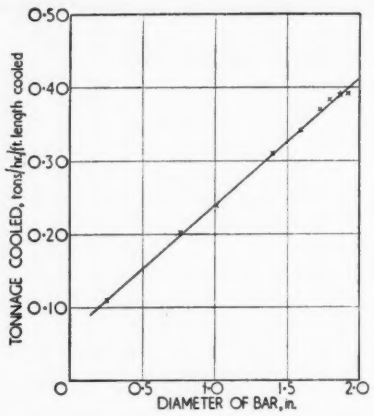


Fig. 18—Effect of bar diameter on tonnage cooled

The sections covered by Figs. 15*a* and *b* were studied on double-sided carry-over type cooling beds similar to that illustrated in Fig. 3, and the sections in Figs. 15*c* and *d* on single-sided roller-type beds generally as shown in Fig. 5. The rounds and nut flats covered by Figs. 15*e* and *f* were cooled on a double-sided bed similar to that shown in Fig. 7 but embodying the pack-annealing mechanism illustrated in Fig. 8*c*; the heavier products were cooled on single-sided beds of a similar type (Figs. 15*g* and *h*).

Figure 18, which illustrates the effect of the bar diameter on the tonnage cooled, shows that the statement (p. 260) that the time required to cool a round bar through a given temperature range varies directly as the diameter, is substantially correct in practice, as the tonnage cooled also varies directly as the diameter.

No practical observations were made on the effect of packing flat products together for slow cooling, but it can be stated that the effect of such packing is to reduce the area of the radiating surface with respect to the mass of the steel, thus reducing the rate of cooling. Therefore, if the height of the pack is increased, the tonnage output of the bed will not necessarily increase, as a result of the further decrease in surface area relative to the mass and the corresponding further decrease in the rate of cooling.

SUMMARY AND CONCLUSIONS

It is not possible to describe in this paper all the ingenious mechanisms that have been devised and used for the handling and cooling of merchant bar mill products. All the mechanical cooling beds and bed mechanisms illustrated are in operation today, and their versatility is such that the bulk of merchant shapes rolled, for the majority of steels in common use, can be adequately handled and submitted to whatever uniform thermal treatment is required by the metallurgist.

It is the author's opinion that, if site conditions and plant layout do not restrict the space available, a double-sided mechanical bed can seldom be justified solely on cooling capacity, nor can it always be justified as a means of providing outlets to duplicate shearing facilities. A double-sided bed is desirable for dealing with twin-strand rolling, and in some circumstances for handling successive cut pieces from a high-speed mill. These justifications will remain until a satisfactory system of run-in tables and transfer mechanism has been evolved by means of which two bars can be simultaneously but separately accepted, transferred, and deposited on the cooling elements without detriment to the mill output. Developments in this direction can confidently be expected.

Acknowledgments

The author wishes to thank the Chairman and Directors of The Brightside Foundry and Engineering Co., Ltd., for permission to publish much of the information contained in this paper, and to express his gratitude to Mr. E. T. Peterson of the Birdsboro Steel Foundry and Machine Company of U.S.A., Mr. G. L. Fisk of New York, and Mr. E. Fors of the Morgan Construction Company, for much helpful information and advice. He is indebted to his colleagues and friends at home and abroad, for information and assistance in the preparation of this paper.

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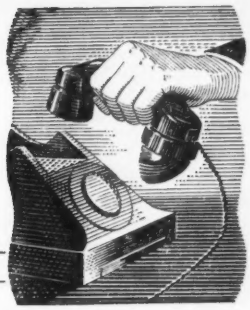
N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Autumn General Meeting, 1951

The Autumn Meeting of the Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 21st and 22nd November, 1951.** The President, Mr. R. Mather, will be in the Chair. A buffet luncheon and light refreshments will be available.

The programme is as follows :

Wednesday, 21st November

Morning Session

10.0 A.M.–10.15 A.M.—Formal business

10.15 A.M.–11.30 A.M.—Joint Discussion on :

"*The Crystal Structure of Graphite in Cast Irons*," by W. S. Owen and B. G. Street (Feb., 1951)

"*The Carbide Phase in Iron–Carbon–Silicon Alloys*," by W. S. Owen (Feb., 1951)

11.45 A.M.–1.0 P.M.—Joint Discussion on :

"*Metallography of Carbon in Silicon–Iron Alloys Containing 4% Silicon*," by E. D. Harry (Mar., 1951)

"*The Variation in Electrical Properties of Silicon–Iron Transformer Sheet*," by S. Rushton and D. R. G. Davies (Mar., 1951)

Afternoon Session

2.30 P.M.–5.0 P.M.—Joint Discussion on :

"*Symposium on Stresses in Moulds* " (July, 1951)

"*Ingot Heat Conservation : Ingot Mould Temperature Measurements*," by R. T. Fowler and J. Stringer (Mar., 1951)

"*Ten-Ton Ingot Moulds : Comparison of Design and Conditions of Use*," by A. Jackson (Mar., 1951)

Thursday, 22nd November

Morning Session

10.0 A.M.–11.0 A.M.—Joint Discussion on :

"*The Production of High-Purity Iron and Iron Alloys on a 25-lb. Scale*," by B. E. Hopkins, G. C. H. Jenkins, and H. E. N. Stone (Aug., 1951)

"*Tensile and Impact Properties of Iron and Some Iron Alloys of High Purity*," by W. P. Rees, B. E. Hopkins, and H. R. Tipler (Oct., 1951)

11.15 A.M.–12.0 NOON—Discussion on :

"*Physical and Mechanical Properties of Segregates in Two Alloy Steels*," by H. M. Finniston and T. D. Fearnehough (Sept., 1951)

12.0 NOON–1.0 P.M.—Joint Discussion on :

"*Structural Transformations in the Tempering of High-Carbon Martensitic Steels*," by K. H. Jack (Sept., 1951)

"*Magnetic Analysis of Iron–Carbon Alloys : The Tempering of Martensite and Retained Austenite*," by J. Crangle and W. Sucksmith (June, 1951)

Symposium on the Corrosion of Buried Metals

The Symposium on the Corrosion of Buried Metals, organized by The Iron and Steel Institute in conjunction with the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry, will be held at the Offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, on **Wednesday, 12th December, 1951.** The programme was given in the September issue of the *Journal*.

Bessemer Drawings

The Council have received, as a result of a generous offer by Mr. H. W. Bessemer, seven large portfolio volumes of drawings relating to patents granted to Sir Henry Bessemer, F.R.S., who was grandfather of the donor.

NEWS OF MEMBERS

▶ Dr. B. R. BANERJEE has left the Bengal Engineering College to take up an appointment in the Engineering Research Department of the Standard Oil Co. (Ind.), Chicago.

▶ Mr. WILFRED BESWICK has retired from the Chairmanship of The Power Gas Corporation, Ltd. His place is being taken by Dr. N. E. Rambush.

▶ Mr. P. A. BLACKWELL has been awarded the degree of B.Sc. in Metallurgy of the University of London.

▶ Mr. D. BRUCE-GARDNER has left the Lancashire Steel Corporation Ltd., Irlam, to become Works Manager of John Lysaght's Scunthorpe Works, Ltd.

▶ Mr. R. BUTLER has transferred from the B.S.A. Group Research Centre, Sheffield, to the Engine and Mechanism Laboratory of the same Company, in Birmingham.

▶ Mr. A. P. GREENOUGH has left the R.A.E., Farnborough, to take up an appointment as Assistant Lecturer in Metallurgy at University College, Swansea.

▶ Mr. K. W. GRIMWOOD has received the degree of B.Sc.(Eng.) in Metallurgy of the University of London.

▶ Mr. V. HARBORD, a partner of Messrs. Riley, Harbord, and Law, has been elected President of the Institution of Mining and Metallurgy for the Session 1952–53.

▶ Mr. J. E. HOLGATE has left Germany and returned to England.

▶ Mr. T. S. LISTER has been appointed Chief Metallurgist of the Machine Tool Division of Messrs. Wickman, Ltd., Coventry.

▶ Mr. C. OVER has been awarded a scholarship to study management technique at the University of Cincinnati.

▶ Dr. W. S. OWEN has left the University of Liverpool to take up an appointment at the Massachusetts Institute of Technology.

▶ Mr. R. N. PARKINS has been awarded the Ph.D. degree of the University of Durham.

▶ Dr. W. I. PUMPHREY has returned from the U.S.A., which he visited on a Commonwealth Fellowship, and

has been appointed Research Manager of Murex Welding Processes, Ltd., in succession to Dr. E. C. ROLLASON.

▶ Mr. B. G. STREET has been awarded the Ph.D. degree of the University of Liverpool, and has taken up a temporary appointment as an Assistant Lecturer in the Department of Metallurgy of the University.

▶ Mr. K. E. A. SUNSTRÖM, formerly Superintendent of Blast Furnaces and Steel Production, Aktiebolaget Bofors, has been appointed Technical Director of Gunnebo Bruks Aktiebolag, Gunnebobruk, Sweden.

▶ Mr. G. L. THOMAS has transferred from Messrs. John Miles and Partners (London) Ltd. to their Bulawayo Branch, Southern Rhodesia.

▶ Mr. L. WALKER has left the Nelson Research Laboratories of the English Electric Co., Ltd., and has become a Development Metallurgist with the Plessey Co., Ltd.

▶ Mr. D. J. YOUNG, Secretary of the Steel Company of Wales, Ltd., will in future be known as Secretary and Comptroller.

Obituary

Mr. O. F. BEST, a partner of Messrs. Best and Blake, on 17th July, 1951.

Mr. FRED CLEMENTS, formerly Chairman of the Park Gate Iron and Steel Co., Ltd., an Honorary Vice-President of The Iron and Steel Institute, and a Bessemer Medallist, on 19th September, 1951.

CONTRIBUTORS TO THE JOURNAL

G. B. Greenough, M.A., Ph.D.—Metallurgy Department, University of Sheffield. Dr. Greenough was educated at Chesterfield Grammar School and at Queens' College, University of Cambridge, where he graduated in Natural Sciences (Part II—Physics) in 1943. He joined the X-ray section of the Royal Aircraft Establishment but returned to the Cavendish Laboratory, on behalf of the Ministry of Supply, to continue his work on the lattice strains in deformed metals, under Professor Sir Lawrence Bragg and Dr. Orowan. He was awarded the degree of Ph.D. for this work. He returned to the Royal Aircraft Establishment in 1947 where he remained until he took a post in the Metallurgy Department of Sheffield University in 1951.

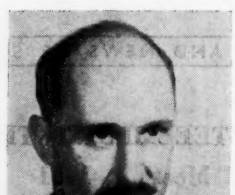
D. W. Dewhirst, M.A., F.R.A.S.—Member of the staff of University Observatories, Cambridge. Mr. Dewhirst was educated at the Grammar School, Keighley, and at Christ's College, Cambridge, where he was elected Exhibitioner in 1945. He graduated in 1947 and became a research student in the Department of Metallurgy, University of Cambridge, where he investigated the metallography and mechanical properties of metals containing non-metallic disperse phases. He obtained his present appointment this year although he has been an amateur astronomer for several years. He is now developing apparatus for solar research.

D. W. Dewhirst

G. B. Greenough

J. D. Hobson, B.Sc., A.R.I.C., A.I.M.—On the staff of Hadfields, Ltd., Sheffield.

Mr. Hobson joined the staff of the Brown-Firth Research Laboratories as an assistant chemist in 1935 and was employed for several years on the analysis of steel and steelworks materials. He was later engaged in the analysis of aluminium and magnesium alloys and carried out research into the chemistry of precision casting by the lost-wax process. He was later in charge of the laboratories devoted to research on the analysis and effect of gases in steel. He took up his present appointment in 1951.



J. D. Hobson

Studying first at the Applied Science Department of Sheffield University and later at the College of Technology, Mr. Hobson was awarded the Associateship in Ferrous Metallurgy in 1939 and the B.Sc. degree of London University in 1944.

Mr. Hobson is a member of the Gases and Non-metallic Inclusions Sub-Committee of B.I.S.R.A. and serves on the Liquid Steel and Nitrogen Groups of the Sub-Committee.

IRON AND STEEL ENGINEERS GROUP

The **Sixteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 4th December, 1951,** commencing at 10.30 A.M.

The Morning Session will be devoted to the discussion of the paper by W. Udall on "*Cooling Beds for Bar Mills*" (this issue, p. 257).

At the Afternoon Session, G. Foster (Dorman Long and Co., Ltd.) will speak on American Rolling Mill Practice.

A Buffet Luncheon will be available as usual.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Corrosion of Buried Metals

A new standard form for recording corrosion failures of buried pipes has been prepared by the Sub-Committee on the Corrosion of Buried Metals. The Sub-Committee has taken over from the Research Co-ordination Committee of the Institution of Water Engineers its work on the corrosion of buried pipe lines, and the new form incorporates the changes which the Institution's experience has shown to be desirable.

The form is available from Mr. E. E. White, B.I.S.R.A., 140 Battersea Park Road, London, S.W.11, and when completed should be returned to the Chemical Research Laboratories of the D.S.I.R., Teddington.

AFFILIATED LOCAL SOCIETIES

Leeds Metallurgical Society

Mr. F. K. NEATH has been elected President of the Leeds Metallurgical Society for the Session 1951–52, in succession to Mr. G. W. GREEN.

Changes of Secretaryship

The following changes have been notified :

Staffordshire Iron and Steel Institute—The Secretary is now Mr. W. C. Churchward, 26 Woodfield Avenue, Wolverhampton, Staffs.

Leeds Metallurgical Society—The Secretary is now Dr. R. Goodacre, The Keighley Laboratories, Ltd., Keighley, Yorks.

MEMOIRS

Oswald F. Best died on 17th July, 1951. He was born in 1876 at Caterham, Surrey, and was educated at Charterhouse School. He then worked for the Dunderland Iron Ore Co., Ltd., which was connected with the Edison Ore Milling Syndicate, Ltd. In 1908 he set up in business on his own account as an electrical and mechanical engineer in connection with steelworks, collieries, etc., for The Wellman Smith Owen Engineering Corporation, Ltd., Simon-Carves, Ltd., and Allen West and Co., Ltd., of which he was a local Director. He was a Member of the South Wales Institute of Engineers and of the Mining Electrical and Mechanical Engineers Association, and was also Senior Liveryman of the Worshipful Company of Bowyers and a Freeman of the City of London. Mr. Best was elected a Member of The Iron and Steel Institute in 1921.

Harold J. Hobson died on 26th June, 1951. He was born in 1895 at Rotherham, and after serving his apprenticeship with the Yorkshire Engine Company he joined Messrs. Sanderson Bros. and Newbould, Sheffield. In 1935 he became Assistant Engineer at the hot-rolling mills of Messrs. Samuel Fox and Co., Ltd., Stocksbridge. where he remained until his death. He was elected a Member of The Iron and Steel Institute in 1947.

Arthur Kipgen, formerly Assistant General Manager of the Arbed Company, died on 11th August, 1951. He was born in 1880 at Roodt-sur-Syr (Luxembourg), and was educated at the Polytechnical University of Aix-la-Chapelle, where in 1903 he obtained a degree in engineering. He spent a short period at the steelworks of Knutange (Lorraine), and a year at the Middlesbrough North Eastern Steel Works, before joining the Rothe Erde Works, Aix-la-Chapelle, as an engineer in 1905. In 1908 he was appointed Chief Engineer of the Thomas Steel Plant at the Dudelange Steel Works (Luxembourg), which in 1911 was taken over by the Arbed Company. He was appointed Chief Engineer of the new steel plant of Arbed-Esch (Luxembourg) in 1913, and returned to the Dudelange Steel Works as Manager in 1918. In 1920 he became Technical Manager at the Central Administration of the Arbed Company in Luxembourg, and in 1926 he was appointed Assistant General Manager, a position which he held until his retirement in 1947.

He was elected Chairman, and later Honorary Chairman, of the Association Luxembourgeoise des Ingénieurs et Industriels ; he became a Member of The Iron and Steel Institute in 1921.

NEWS OF SCIENCE AND INDUSTRY

Institution of Mining and Metallurgy

The Council of the Institution of Mining and Metallurgy announce the election of Mr. Vernon Harbord, A.R.S.M., as President for the Session 1952–53. He will take office at the Annual General Meeting to be held on 15th May, 1952.

Mr. Harbord is a partner of the firm of Messrs. Riley, Harbord, and Law, Consulting Metallurgists. During the last 18 months of the war he was metallurgical adviser to the Armament Research Department.

Institute of Metal Finishing

The first President of the newly incorporated Institute, which has taken over the function of the Electro-depositors' Technical Society, is Mr. H. Silman, Chief Chemist of Joseph Lucas, Ltd., Birmingham.

City and Guilds of London Institute

H.R.H. The Duke of Edinburgh, K.G., F.R.S., has graciously accepted the office of President of the City and Guilds of London Institute for the Advancement of Technical Education, to which he was elected at a Special General Meeting on 21st September, 1951.

International Industrial Research Institute

An international industrial research institute, to be known as the Battelle International Institute, is shortly being established by Battelle Institute, Columbus, Ohio, U.S.A., to serve the European economy. The Institute will establish research investigations in existing research institutes of Europe and in European universities and technical schools. It will also operate its own laboratories on the Continent, the exact locations of which will depend upon the outcome of negotiations now in progress.

Mr. John S. Crout, for many years Assistant Director of Battelle, will be the Executive Director of the new Institute.

International Materials Conference

The Report of the Joint Sub-Committee on Utilization of Manganese, Nickel, Cobalt, Tungsten, and Molybdenum was presented at a meeting held on 17th August, 1951. The Sub-Committee consists of metallurgical experts from nine member countries, and is charged with examining all practicable measures of effecting the highest degree of economy in the use of the five elements, including the use of substitutes and the salvage of waste products. This is probably the first time that a group of metallurgists have met as the accredited representatives of their Governments to discuss conservation measures.

The Chairman of the Sub-Committee is Mr. K. H. J. Clarke, and the Vice-Chairman is Mr. F. F. Franklin. The United Kingdom representatives are Mr. E. H. Bucknall and Mr. J. F. Sewell. The Report was prepared by a drafting group under the Chairmanship of Mr. Bucknall.

The agenda included a review of existing specifications, the problems of substitution and limitation (with special reference to end uses), salvage, and the use of scrap, in certain main fields of utilization. These main fields are : ferro-alloys ; steels and cast irons including stainless and heat-resisting steels, tool steels, low-alloy steels, and alloy cast irons ; non-ferrous alloys ; and catalysts and chemicals.

Mechanical Engineering Research

The first report, entitled "Mechanical Engineering Research, 1947–50," issued by the Mechanical Engineering Research Organization has recently been published for the Department of Scientific and Industrial Research by H.M.S.O.

Since the report was prepared, the workshop, the boiler house, and the main part of the Properties of Materials laboratory have been completed at East Kilbride. The laboratory will be used at first as a general purposes building available for experimental work on materials, mechanics of solids, fluid flow, heat transfer, and mechanics of formation.

Long-term and short-term research on creep is being undertaken, and fluctuating-stress tests have been

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carried out on typical steam-plant steels under peak load and temperature conditions.

Gauging and Measuring Screw Threads

A new series of handbooks under the general title "Notes on Applied Science" is being prepared by the National Physical Laboratory. The first handbook, "Gauging and Measuring Screw Threads," has recently been published for the Department of Scientific and Industrial Research by H.M.S.O., and is a comprehensive survey of measuring and gauging methods for use in the production and measurement of accurate screw threads and especially of screw gauges. The handbook contains the most up-to-date material available, and covers all current requirements.

Summer School on Welding Design and Engineering

The British Welding Research Association held a successful summer school from 25th May to 2nd June, 1951, at Ashorne Hill near Leamington Spa. They have decided to hold a similar function next year and have made provisional bookings at the same place.

Beilby Memorial Awards

From the interest derived from the invested capital of the Sir George Beilby Memorial Fund, at intervals to be determined by the Administrators representing the Royal Institute of Chemistry, the Society of Chemical Industry, and the Institute of Metals, awards are made to British investigators in science to mark appreciation of records of distinguished work. Preference is given to investigations relating to the special interests of Sir George Beilby, including problems connected with fuel economy, chemical engineering, and metallurgy, and awards are made, not on the result of any competition, but in recognition of continuous work of exceptional merit, bearing evidence of distinct advancement in science and practice.

In general, awards are not applicable to workers of established repute, but are granted as an encouragement to younger men who have done original independent work of exceptional merit over a period of years.

The Administrators are empowered to make more than one award in a given year if work of sufficient merit by several candidates is brought to their notice. In 1950 two awards, each of one hundred guineas, were made to Mr. W. A. Baker and Dr. G. Whittingham (*see* July issue of the *Journal*, p. 304).

Consideration will be given to the making of an award or awards from the Fund early in 1952 and the Administrators will therefore be glad to have their attention drawn to outstanding work of the nature indicated, not later than 31st December, 1951.

All communications on this subject should be addressed to the Convener of the Administrators, Sir George Beilby Memorial Fund, Royal Institute of Chemistry, 30 Russell Square, London, W.C.1.

Essay Competition

The North Wales Metallurgical Society is offering prizes of five guineas each for two papers on metallurgical subjects. The closing date is 1st February, 1952. Full particulars may be obtained from the Hon. Secretary, Mr. S. Weir, 67 Wepre Park, Connah's Quay, Nr. Chester.

Steel Company of Wales, Ltd.

The Orb Works at Newport, which has been known as the Steel Company of Wales (Lysaght Works) Ltd., will in future be operated as the Lysaght Division of the Steel Company of Wales, Ltd.

DIARY

1st Nov.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Finishing Processes in the Manufacture of a Bicycle*," by T. Parry—Star and Garter Hotel, Wolverhampton, 7.30 P.M.

1st Nov.—LEEDS METALLURGICAL SOCIETY—"*Some Structural Aspects of Recrystallization*," by R. Eborall—University, Leeds, 7.0 P.M.

2nd Nov.—INSTITUTION OF MECHANICAL ENGINEERS—"*Some Factors Affecting Wear on Cemented Carbide Tools*," by E. M. Trent—Storey's Gate, St. James's Park, London, S.W.1, 5.30 P.M.

9th Nov.—LIVERPOOL METALLURGICAL SOCIETY—"*What is a Dislocation?*" by B. A. Bilby—Electricity Service Centre, Whitechapel, Liverpool, 7.0 P.M.

13th Nov.—LIVERPOOL METALLURGICAL SOCIETY (Joint Meeting with the Institute of Welding)—"*Welding Metallurgy*," by E. C. Rollason—City Technical College, Byrom Street, Liverpool, 7.0 P.M.

13th Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Simple Theoretical Aspects of Ferrous Metallurgy*," by K. W. Andrews—Grand Hotel, Sheffield, 7.0 P.M.

14th–15th Nov. — RUBBER-STICHTING — International Symposium on Abrasion and Wear—Rubber-Stichting, Oostsingel 178, Delft, Holland.

16th Nov.—INSTITUTION OF MECHANICAL ENGINEERS (Thomas Hawksley Lecture)—"*Some Fuel and Power Projects*," by H. Roxbee Cox—Storey's Gate, St. James's Park, London, S.W.1, 5.30 P.M.

16th Nov.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Basic Refractories*," by J. R. RAIT—39 Elmbank Crescent, Glasgow, 6.45 P.M.

19th Nov.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*American Alloy Steel Rolling Practice*," by R. Stewartson (Joint Meeting with the Iron and Steel Engineers Group)—University, St. George's Square, Sheffield, 7.30 P.M.

20th Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Spectrographic Analysis—Refractories and Alloy Steels*," by G. L. Mason and R. H. Tyas—Grand Hotel, Sheffield, 7.0 P.M.

21st–22nd Nov.—IRON AND STEEL INSTITUTE—Autumn General Meeting—4 Grosvenor Gardens, London, S.W.1, 10 A.M.

25th Nov.–1st Dec.—24TH INTERNATIONAL CONGRESS OF INDUSTRIAL CHEMISTRY—Paris.

TRANSLATION SERVICE

(The previous announcement was made in the October, 1951, issue of the *Journal*, p. 178).

TRANSLATION IN COURSE OF PREPARATION

The purpose of this announcement is merely to give advance notice of the intention to prepare translations, and orders should not be sent in until a further announcement appears under "Translations Available."

(French). P. ROCQUET and M. OLETTE: "Growth of Cast Irons. Application to the Study of Ingot-Mould Irons." (*Fonderie*, 1951, vol. 67, July, pp. 2565–2577).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

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MINERAL RESOURCES

The Northampton Sand Ironstone—Stratigraphy, Structure and Reserves. S. E. Hollingworth and J. H. Taylor. (Department of Scientific and Industrial Research, Memoirs of the Geological Survey of Great Britain, 1951 : H.M. Stationery Office).

Nepheline Syenite and Iron Ore Deposits in Greenland. F. Illingworth. (Mining Magazine, 1951, vol. 84, Jan., pp. 24–27). Mineral resources and mining developments in Greenland are surveyed. Some details of composition are given for zirconium-bearing nepheline syenite and associated rocks from which niobium has been reported. Data are also given of promising magnetite deposits at Gronnedal which are being explored.—E. C.

The Iron Ore Problem of the Western Hemisphere. K. E. Dittmann. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 73–83). Based on the iron requirements of the U.S.A. and the other industrial countries, the present position and future possibilities of fulfilling the iron ore needs of the U.S.A. from home and foreign ores deposits are discussed. The increasing scarcity of rich home ores has necessitated the undertaking of beneficiation and treatment of leaner ores. New deposits in Canada, in Central and South America, and Africa have considerably extended the sources of supply but have increased transport charges over new routes, including the building of a new water-way from Lake Superior to the Atlantic.—J. P.

ORES—MINING AND TREATMENT

New Mining Methods Tested by Menominee Range Iron Ore Producers. P. D. Pearson and W. W. Jamar. (Mining Engineering, 1951, vol. 190, Apr., pp. 337–346). A survey is made of recent trends and developments in iron ore mining practice on the Menominee Range, Michigan, where semi-hard hematite and limonite ores are worked. Details are given of drilling techniques and performances, single-use bits being most suitable for the type of ore. Relative merits of conveyor belt and rail car underground haulage are discussed. For surface stockpiling, diesel-powered, trackless dumping cars offer ease of operation and low maintenance costs. Mining practices include long-hole drilling, electric blasting with millisecond delay caps, and large powder charges.—E. C.

Trackless Mining Succeeds in Heavy Abrasive Iron Ore. (Engineering and Mining Journal, 1951, vol. 152, Jan., pp. 58–62). Methods and equipment for underground trackless mining of iron ore in the Birmingham, Alabama, region are described. They show increased production, greater safety, reduced timbering costs, greater overhead clearance, and better ventilation. Mine layouts of trackless panel, and conventional room and pillar mining are compared. Roof bolting and rubber-tyred or crawler-mounted air-driven drill 'jumbos,' are now employed; bulldozers are used extensively underground. Trackless, crawler-mounted loaders, adapted for loading heavy iron ore, reach loading rates of 5 to 6 tons/min. Loader to surface conveyance is effected by trolley train and 15-ton skip.—E. C.

New 15-Ton Unloader for Imported Iron Ores. W. B. MacLean. (Engineering and Mining Journal, 1951, vol. 152, Mar., p. 79). A brief description, dimensions, and data are given of a new, direct current, 15-ton ore unloader installed on the east coast of U.S.A. Its capacity is 1100 tons/hr.—E. C.

Adjustable Voltage Drives for Ore Handling. C. B. Risler. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 102–107). The author discusses the features available with an adjustable voltage drive, not available with other drive systems and the application of these drives to bulk-handling equipment. Drive systems are described as well as motors, motor-generator sets, and controls. Adjustable voltage drives have many advantages which result in economical operation, reliability and low maintenance costs.—M. D. J. B.

Handling Imported Ore. G. H. Atwood. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 120–125). The ore unloading and handling facilities at the large import pier at Curtis Bay in the Port of Baltimore, designed by the Baltimore and Ohio Railroad Company and operated by the Dravo Corp., Pittsburgh, Pa., are described. A 12,000-ton vessel can be unloaded in only 6 hr. by means of 15-ton grabs which unload on to a grilled hopper bin which in turn feeds the ore on to a conveyor belt carrying the ore to a scale house where it is weighed and loaded into railway wagons. The installation described represents a modern high-speed efficient ship unloading and wagon loading system.—M. D. J. B.

Mineral Separation by an Electro-Chemical Magnetic Method. H. C. G. Vincent. (Nature, 1951, vol. 167, June 30, p. 1074). Minerals of relatively high conductivity may be extracted from rock powders by the electrodeposition of iron followed by magnetic separation. Clean separation is possible for pyrites, galena, graphite, hematite, and manganese ores and the method is applicable where other processes such as flotation are inadequate.—A. G.

Use of Statistical Methods for Comparison of Iron Ores. A. Palazzi and R. Sacerdote. (Metallurgia Italiana, 1951, vol. 43, May, pp. 180–184). The authors study the problem of blast-furnace burdens in relation to transport and stocking

facilities. One or more characteristics of fundamental importance to blast-furnace operation are examined in a number of ores and a statistical analysis is made of these characteristics to ascertain whether their occurrence follows a normal distribution. The data are classified and card indexed. The variation in distribution is also examined in relation to time. From this investigation, it has been possible to determine which of the ores are identical with respect to the characteristics examined, by simultaneously comparing the mean and standard deviations.—M. D. J. B.

Comparative Tests with Different Methods of Separation for Magnetic Analysis. S. Mörtsell. (Jernkontorets Annaler, 1950, vol. 134, No. 12, pp. 572–581). [In Swedish]. A new hand magnet for classifying ground ores, which gives a separation in good agreement with the Davis magnetic tube tester, is described.—B. S. E.

Krupp-Renn Process Urged for Iron Ore Beneficiation. P. E. Henry, C. F. Ramseyer, and J. R. Miller. (Steel, 1951, vol. 128, Mar. 12, pp. 92–98). The operation of a Krupp-Renn rotary kiln installed at the Czech United Steels Co. is described. This type of plant makes possible the recovery of iron present in the form of silicates in the ore which cannot be recovered by any other beneficiation process. The kiln can be separately heated by the cheapest available fuel, but most of the sulphur present in the fuel enters the burden. Product of the kiln is a sort of glassy slag which is ball-milled, screened, and passed over magnetic separators to rescue the iron; non-magnetic tailings become commercial crushed slag.—A. M. F.

Beneficiation of Taconites by Pyro-Metallurgy. R. G. Wuerker. (Mining Engineering, 1951, vol. 190, Jan., pp. 25–26). The Krupp-Renn process of treating low-grade iron ores in rotary gas-swept kilns is described.—E. C.

Concentration of Carbonate and Oxide Manganese Ores from Silver Bow, Jefferson and Park Counties, Mont. K. C. Dean and J. V. Batty. (United States Bureau of Mines, March, 1951, Report of Investigations 4767). Two samples of ore from the Tzarena claim (6·05% and 10·65% Mn respectively), which is part of one of the largest and most extensive known rhodochrosite deposits in the world were investigated. Fine grinding was essential to produce a marketable product. Coarse gravity concentration recovered approx. 80% of the manganese in a concentrate with a rejection of 34·4% to 42·6% of the original weight. Flotation treatment followed by sintering gave a recovery of manganese of between 55·1% and 50·3% with a 44% Mn and 48% Mn content respectively. Addition of a second concentrate gave a recovery between 69·5% and 80·5% of the manganese in concentrates containing 40% and 44% Mn. Three samples of ore from the Minnie Jane property containing 24·5%, 16·6%, and 10·8% Mn respectively were concentrated by sulphide and fatty acid flotation and one sample also by cationic flotation of SiO_2. The two samples of ore from the McClellan-Eackley lease (34·8% Mn) were very similar in composition. Concentration by ore dressing was not effective owing to the extremely intimate association of manganese and iron.—B. J. B.

Concentration of Oxide Manganese Ores from the Steelville and Susie Q Claims, Beaver County, Utah. K. C. Dean and K. C. Vincent. (United States Bureau of Mines, May, 1951, Report of Investigations 4785). The work described was carried out on 2-ton samples. Experimental details of the following tests are given: Washing and sizing, tabling, flotation, and magnetic separation. The results of testing the Steelville deposits (28·8% Mn) indicate that only a small portion of the manganese minerals in the ore was sufficiently free from interspersed fine particles of silica and calcite to be recovered in high-grade manganese products. Some slimy and porous gangue could be removed by attrition grinding. Over a fourth of the Susie Q ore (8·5% Mn) was reduced to slime during treatment by wetting alone. This sliming was non-selective and no concentration of the metallic constituents occurred.—B. G. B.

Pelletising Iron-Ore Fines and Concentrates: Review of Some Recent Work. (Iron and Coal Trades Review, 1951, vol. 162, May 11, pp. 1099–1102). This article reviews the modern methods of pelletizing iron-ore fines and concentrates for smelting in the blast-furnace, reference being made to the work carried out at the Mines Experiment Station, Minnesota, and at the Swedish Institute of Technology. Factors determining the quality of the pellet, including particle-size distribution, water content, rolling procedure, and drying and firing methods are discussed, and consideration is given to the theory that the binding forces operating in the pellet are due to capillary action and surface tension phenomena.—G. F.

The Possibilities of Utilising Indigenous Ores. M. Szele. (Kohászati Lapok, 1951, vol. 6, Feb., pp. 26–30). [In Hungarian]. The author reviews briefly the availability of ores in Hungary and their utilization possibilities. He describes their location, quality, and extent to which they are utilized, also experiments to find better methods of utilization. The Rudabanya iron ores are the most important. There are considerable deposits of manganese ore in the Urkut area; the raw ore contains 16 to 33% Mn; after washing it contains about 38 to 40% Mn and about 50% of this is in 2·5-mm. particles. Another important material containing iron is pyrites cinder. A suitable method has now been found for reducing the copper in this material from 1·8% to 0·1–0·15%. The recovery of copper, gold, and silver from the pyrites is now possible.—E. G.

Utilisation of Indigenous Low-Grade Ores. L. Visnyowszky. (Kohászati Lapok, 1951, vol. 6, Mar., pp. 63–66). [In Hungarian]. The author believes that wehrlite could not be utilized economically as an iron ore, but its use for producing titanium and vanadium should be investigated. Ores of the Debrecen region (containing 22–25% Fe, 3–6% Mn, 1–2·5% P, 25–35% SiO_2) and other poor ores are not suitable. Utilzation of pyrites cinder is advantageous. For steel production it is necessary to reduce the copper content, which can be done, but it is more advantageous to use it for production of pig for iron castings.—E. G.

Preparation of Rudabanya Ores. B. Vécsei. (Kohászati Lapok, 1951, vol. 6, Mar., pp. 56–62). [In Hungarian]. Rudabanya ores are the most important iron-ore deposits available in Hungary. The author gives the opinions of Hungarian and foreign consultants on their best utilization and reports on post-war Hungarian experimental work. The deposits consist of limonite, siderite, and ankerite, and preparation is essential as the iron content is low and fluctuates greatly. Attention is being paid to the extraction of barytes. The results of laboratory and full-scale tests are given. By roasting in a reducing atmosphere the iron content is increased to 35·8%; the residue contains 77·70% $BaSO_4$ and 3·74% Fe. By roasting and subsequent magnetic separation the iron content is increased from 23·6% to 40–42% with 7–9% barytes, the residue containing 3·8–7·7% iron and 45 to 67% barytes.—E. G.

FUEL—PREPARATION, PROPERTIES, AND USES

Efficient Utilisation of Fuel in the Iron and Steel Industry: Research at Leatherhead Will Benefit Heavy Industries. (Iron and Coal Trades Review, 1951, vol. 162, June 22, pp. 1435–1438). In this article, a summary is given of Sir Charles Ellis's Presidential Address to the British Coal Utilisation Research Association, followed by brief accounts of some of the Association's current research. This includes work on the following: Steam-raising in industry, including deposits and corrosion in water-tube boiler plants; gas producers, including automatic control; gasification of slurry and other low-grade coal fines; development of the downjet burner; the cyclone furnace; and the solvent extraction of coal.—G. F.

Increasing Combustion Efficiency in the Steel Industry. J. G. Sparks. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 89–94). After briefly stressing the need for the highest possible efficiency in all fuel-combustion processes, the author describes a 'heat prover' which measures waste caused by air deficiency or dilution. This instrument is designed to measure the combustion efficiency of any type of furnace using any fuel. Its applications to the open-hearth furnace to determine air infiltration and to check fuel-air ratio controls are described. The use of the heat prover in assessing the combustion efficiency of soaking pits and reheating furnaces is also discussed. Consideration is given to the round soaking pit; the rectangular or square Amco pit; the rectangular and square Swindell and surface-combustion pits; and to batch and continuous reheating furnaces.—M. D. J. B.

Training Open-hearth Personnel in Use of Fuels. B. Dagan. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 288–289). A syllabus of eight lectures on combustion, suitable for open-hearth personnel, is outlined.—F. C.

Economy in Fuel Consumption in the Iron and Steel Industry. J. Pinheiro da Fonseca. (Boletim da Associação Brasileira de

Metais, 1950, vol. 6, Oct., pp. 331–345). [In Portuguese]. The author discusses methods of reducing fuel consumption and their application to sintering, pelletizing, high top pressure, oxygen-enriched air, low-shaft furnaces, and direct production of sponge iron. As regards Brazil, he concludes : (1) Reafforestation schemes must be expedited to ensure supplies of charcoal ; (2) sintering must be developed ; (3) high top pressure and oxygen-enriched blast must be considered and, in some cases, adopted ; (4) the following factors must be given attention in each region : Ore quality ; cost and availability of power ; and cost and quality of fuel. Sweden is carrying out experiments using Brazilian raw materials.—R. S.

Calculation of Flue Loss. (Gas Times, 1951, vol. 68, July 13, pp. 30, 35). The information given in this short article is reproduced from Report No. 50/2/39 D.083 of the Industrial Gas Development Committee. A method of calculation of flue loss is put forward in which the only gas composition data required are the 'CO_2 produced' and 'H_2O produced.' The derivation of an accurate formula is given, and simplified versions for use in the field are suggested.—P. M. C.

The Aerodynamic Basis for Gas Burner Design. V. Tatarinov. (Steel Processing, 1951, vol. 37, Apr., pp. 189–191). The author quotes a complex formula from which, with the aid of two nomograms, the velocities of the air and gas mixture in the diffusor throat and at the burner muzzle may be calculated.—P. M. C.

Automatic Control Systems for Multi-Fuel Firing. R. L. Willis. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 84–88). The author presents typical methods of multi-fuel control. The need to consume fuels produced in the production of coke and pig iron in order to keep fuel purchases to a minimium are considered and the basic control system for multi-fuel firing is described. It application to boilers is considered in detail and schemes are shown for using blast-furnace gas and a stoker to fire boilers, as well as three-fuel arrangements. Fuel control systems for open-hearth and reheating furnaces are also dealt with. In conclusion, it is shown how multi-fuel control enables the maximum economic gain from fluctuations in fuel costs to be obtained.—M. D. J. B.

Metallic Recuperators Adapted to Rolling Mill Furnaces. M. Saulnier. (Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1949, Aug.–Oct., pp. 417–427). Metallic recuperators are described and compared with other types. Their advantages over regenerators are continuous operation, rapid response to control, suitability with high-pressure burners, and quick replacement of defective parts ; and they are superior to brick recuperators in being small and light, giving good heat transfer without the leaks that occur in thin brickwork ; they withstand vibration. On the other hand the bending of metals due to thermal expansion, the greater damage caused by excessive heat, and the problem of carbon deposition from carbon monoxide need special attention. The author goes on to describe the Liesen and Newton forms of the needle-type recuperator. At the Louvroil des Forges et Aciéries du Nord et de l'Est works the Liesen type was used for a soaking pit, and found unsuitable for gas ; but by using air and protecting the hottest part with ciment fondu it was made satisfactory. The Newton model, is briefly described. The tubular type of recuperator is represented by the Aubé and the canal designs, the latter being intended for very large furnaces. In the Aubé, air may be heated to 450° C. in mild steel, or to 750° C. in chromium steel tubes. A description of the performance of one of these belonging to the Société Escaut-et-Meuse is given in an appendix : the air is heated to 300° C. and no trouble was found with the tubes in 17 months, but the horizontal surfaces collect dust.—N. McE.

The Metallic Recuperators at the Röchling Works at Volklingen. M. Aunervier. (Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1949, Aug.–Oct., pp. 410–414). Details are given of the design and performance of recuperators attached to reheating furnaces, and of a Cowper blast-furnace stove. They are of the Schack type, in which the bricks are replaced by plain carbon steel and chromium steel tubes. A needle-type recuperator is also mentioned.—N. McE.

Structure of Coal and Coke. Z. Szklarska. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 2, pp. 161–171). [In Polish]. The latest publications dealing with the structure of coal and coke are reviewed. X-ray studies of turbostratic structure are described in some detail. The mobile and rigid turbostratic systems have been defined. Colloidal properties of coal and its petrographic classification are briefly mentioned. The mechanism of formation of coke structure as interpreted from heat of wetting, electrical conductivity measurements, and X-ray studies is described.—V.G.

Coal Preparation in England and Holland. J. Griffen. (Mining Engineering, 1951, vol. 190, Feb., pp. 183–184). Methods of coal preparation in Britain are outlined and described as superior to American practice regarding mechanical cleaning of large coal, use of heavy-media processes with difficult coals, froth flotation of slurries, and use of coagulants for wash-water clarification. Problems and trends in Dutch coal preparation are summarized.—E. C.

The Thermal Drying of Coal. W. R. Chapman and L. W. Needham. (Journal of the Institute of Fuel, 1951, vol. 24, Mar., pp. 51–60). In America and Canada coal is dried to prevent freezing, to reduce freight costs in long hauls, and to increase the calorific value. Fine coals, such as froth-flotation products, are dried to assist handling and to reduce the moisture charged to coke ovens whilst dry coal makes weather-resistant briquettes which do not deteriorate during heat-treatment. British thermal driers operating with an average fuel consumption of 42 therms/ton cost 10*s.* per ton of water removed or 15*s.* including interest and depreciation. Bunkers and centrifuges are much cheaper provided the water content of the product may exceed 6%. Indirect heating by the Fleissner process, the Lopulco drier and the tubular driers are used, especially in Continental brown-coal mines, to lessen fire and overheating risks. The Ruggles-Coles, the Büttner and the Pehrson driers are direct heating rotary drum types suitable for coarse coals above $\frac{1}{8}$ in. The Büttner turbo and the Reol tray driers save floor space but degrade the coal, whereas the Baughman Verti-Vane, the Link-Belt Multi-Louvre, and the Modave cascade driers cause less breakage but require a very uniform feed. In America and Canada screen driers like the McNally-Vissac are used fairly extensively. Flash driers are used for drying slurry or filter cakes before pulverization and, in Germany, for drying crushed lignite before briquetting.—E. J. B.

The Effect of Coke Breeze Additions to Coal Blends on the Quality of Metallurgical Coke. F. Byrtus. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 2, pp. 85–95). [In Polish]. The effect of an addition of 6% of coke breeze to blends of Upper Silesian coals on the quality of metallurgical coke was investigated on a semi-industrial scale. Coke-breeze blending increased the crushing resistance, but lowered the abradability of the coke. To evaluate the suitability of this coke for blast-furnaces, measurements of compactness, coefficient of uniformity of lumps before and after the Sundgren test, and the resistivity to gas flow were made.—V. G.

The Continuous Determination of the Water Content of Coking Coal. H. R. Asbach. (Glückauf, 1951, vol. 87, Jan., pp. 18–22). A recording instrument is described in which advantage is taken of the high dielectric constant of water for determining the moisture in coking coal, brown coal, and hard coal. The probe of the instrument consists of a condenser constructed of six copper strips embedded side-by-side in a flat insulating pad and covered by a tight-fitting glass lid. Alternate strips are connected so that two sets of three strips form one electrode each. The condenser is built into the coal chute so that its top glass surface is flush with the bottom surface of the chute. Coal passing over it cuts the lines of force effecting a change in the capacity of the condenser. Most of the lines of force lie close to the electrodes so that variations in the height of the coal layer introduce no appreciable errors. The recording chart is calibrated experimentally over the useful range of water contents. Differences between recorded moisture contents and moisture contents determined on the same samples by drying methods were of the order of $\pm$ 0·2% at any point of the calibrated range.—P. F.

Density Control of Coal Charged to Coke Ovens. C. W. Stahl and J. K. Kurtz. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 93–99). This paper shows from actual experience, what can be accomplished in bulk-density control by the careful addition of oil and water at a coke plant and indicates the limitations of such control. A description is given of the operating procedure, equipment, and results of the bulk-density control system installed at the coke ovens of Bethlehem Steel Co. Figures show that before the control system was placed in operation, variations were as much as one ton per coke-oven charge, reflecting changes in moisture,

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and that since control was established, the variation has not exceeded 0·10 ton.—M. D. J. B.

Memorandum on the Conservation of Metallurgical Coal by the Tata Iron & Steel Co., Ltd. and the Indian Iron & Steel Company Limited. (Tisco Review, 1950, vol. 18, May, pp. 128–130, 138–141, 160–163). The paper deals with the influence of the purity of the coke, as revealed by its ash content, on blast-furnace production and coke consumption. Each increment of 1% in the ash content of the coke decreases the production of pig iron by about 3–6%, increases coke consumption by about 4–5%, and increases limestone consumption per ton of pig iron by about 5%. In appendices there are: (*a*) Specifications of coking coal and coke for making basic pig iron; (*b*) formulæ for calculating the influence of coke and coal ash on coke consumption and pig-iron production; and (*c*) an explanation of the 'Tisco-Isco' method for determining coking indices.—R. A. R.

Review of the Coking and By-Product Industry in Australia and Its Further Development. W. Farafonow. (Australasian Engineer, 1951, Mar. 7, pp. 70–73). The author first outlines the by-products of the coking industry, and describes briefly the several types of coke oven in general use. Then follows a brief history of the industry in Australia and an appraisal of the present position in comparison with other principal industrial countries. In 1948 Australia produced 1,244,000 tons of metallurgical coke as compared with 67,444,000 tons in the U.S.A. and 15,580,000 tons in Great Britain. Suggested procedure for the near-future development of the Australian industry is given.—P. M. C.

The Thermal Efficiency of the Distillation and Gasification of Coal. F. J. Dent. (Institution of Gas Engineers: Gas World, 1951, vol. 134, July 28, pp. 71–76). The requirements of an ideal fuel gas production process are enumerated. Methods of carrying out distillation and hydrogenation, and gasification of solid residue are suggested. The latter include the use of oxygen and steam, the decomposition of methane from the residue by steam, and a fluidized version of the iron/steam process for hydrogen production, using the residue to regenerate the iron. Some thermal calculations are made and flow diagrams are given. The thermal efficiency of gas production by carbonization is 65%, but this new process should attain 80%.—T. E. D.

TEMPERATURE MEASUREMENT AND CONTROL

General Notes on the Automatic Control of Temperature. J. Bernot and P. Lambert. (Journal du Four Electrique, 1950, vol. 59, Nov.–Dec., pp. 147–149; 1951, vol. 60, Mar.–Apr., pp. 48–50). The first part deals with the mathematical considerations involved and the methods available for temperature measurement. Examples are given in the second part of the mechanical operation of controller circuits based on different methods of temperature indication.—B. G. B.

Temperatures of Open-Hearth Bottoms Measured. R. B. Snow. (Iron Age, 1951, vol. 167, Feb. 1 pp. 103–106; Feb. 8, pp. 98–100). The results reported in this paper are based on thermocouple measurements taken in six open-hearth bottoms and extensive core drilling. Rammed bottoms of the same depth show similar thermal gradients providing equal insulation is used and all bottoms are eroded to about the same depth after limited service regardless of composition or burning-in schedule. A suggested construction for a 41-in. deep hearth is given for which fast burning-in is recommended.—A. M. F.

Reference Tables for Thermocouples. H. Shenker. J. I. Lauritzen, jun., and R. J. Corruccini. (United States Department of Commerce, National Bureau of Standards, Circular 508, 1951, May 7). Expanded reference tables of millivolts against degrees Fahrenheit and Centrigrade are given for the common thermocouples: Pt/Pt–10% Rh, Pt/Pt–13% Rh, Chromel–Alumel, copper Constantan and Chromel–Constantan. The tables incorporate recent changes in electrical units and temperature scale.—T. E. D.

Operation and Maintenance of Electronically Operated Instrument Equipment. J. R. Green. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 102–107). A review is given of the industrial usage, operating characteristics, performance, and principles of maintenance of electronic potentiometers for the measurement of temperatures. The principles of the mechanically balanced and electronically balanced instruments are described and the advantages of the latter type considered in detail. The characteristics of the electronic potentiometer which make it particularly advantageous in steelworks are continuous balance, few moving parts, unaffected by vibration, higher accuracy, faster operation, narrow spans, parallel operation, and lock-in position. Modern design on the unit principle greatly simplifies maintenance procedure.—M. D. J. B.

REFRACTORY MATERIALS

Silica Brick Manufacture: New Mechanized Plant at Landore. L. H. Williams. (Iron and Coal Trades Review, 1951, vol. 162, May 25, pp. 1189–1193). A description is given of the new silica-brick making plant at the Landore works of Richard Thomas and Baldwins, Ltd., which is one of the most modern in Britain. The plant is designed to produce seven million refractory bricks a year and it incorporates a unique continuous tunnel kiln, with the latest and most efficient practice. Details of the plant and its operation are given, and prominence is given to working conditions for the operators.—G. F.

Drying of Refractory Materials. A. L. Roberts. (Journal of the Institute of Fuel, 1951, vol. 24, May, pp. 126–128). After indicating the part played by drying in the production of refractories the author gives typical rate-of-drying curves and shrinkage data. He then discusses the characteristics of the constant-rate period, dealing particularly with the precautions adopted to prevent cracking and concludes with brief references to the modern drier and to the use of radiant-heating methods for drying refractories.—J. P. S

The Tasks of the Refractory Industry to Satisfy the Requirements of the Iron and Steel Industry. B. Selmeczi. (Kohászati Lapok, 1951, vol. 6, Mar., pp. 70–72). [In Hungarian]. In most fields of refractory production Hungarian developments lag far behind other countries. Sövegjarto and Cser have developed a method of producing stabilized dolomite refractories with satisfactory properties; further tests are required before these can be applied on a larger scale to replace magnesite refractories produced from imported raw materials—E. G.

Constitutional Changes in Fireclay on Heating. J. M. Gworek and Helen Towers. (Journal of the West of Scotland Iron and Steel Institute, 1945–46, vol. 53, pp. 130–155). Investigations on a fireclay which expanded on firing so that the bricks made from it were oversize and frequently cracked are reported. The changes occurring in kaolinite clays on heating are briefly reviewed. The reason for this trouble was a sudden expansion at about 1200° C. This is illustrated by a number of dilatation curves. In some clays this expansion could be eliminated by using a slower heating rate, but although fine grinding, high moulding pressures, slow heating rate, and reducing atmosphere all raised the temperature at which the expansion occurred, with one clay trouble could only be eliminated by the addition of a fairly large proportion of grog. This phenomenon is discussed and it is suggested that the expansion is due to the growth of needle-like mullite crystals, the formation of mullite being catalysed by the relatively high proportion of Fe_2O_3 contained in the clay. The exothermic reaction in kaolin at 950° C. is accompanied by an increase in volume of the solid particles, a fact not previously recorded. No similar changes take place in γ-alumina, amorphous silica, or a mechanical mixture ($Al_2O_3 + 2SiO_2$). It is concluded from X-ray examination that the kaolinite structure exists up to the endothermic reaction at 540° C. above the temperature of which there is no evidence of any structure until that of γ-alumina at the exothermic reaction. Above 1170° C. only the mullite structure is present. γ-alumina formed from kaolinite during calcination was stabilized by silica so that α-alumina does not form.—P. C. P.

The Specific Heats of MgO, TiO_2, and ZrO_2 at High Temperatures. J. S. Arthur. (Journal of Applied Physics, 1950, vol. 21, Aug., pp. 732–733). Mean specific heats were determined from 20° to 800° C. for MgO, TiO_2, and ZrO_2. True specific heats were then calculated assuming that $C_T = A + BT + CT^2$. At 350° C. the true specific heats were calculated to be 0·276 for MgO; 0·210 for TiO_2; and 0·140 for ZrO_2; where C_T = true specific heat, T = temperature and A, B, and C are constants. The accuracy of the specific heats was judged to be ± 2·0%.—J. P. S.

Ladle Linings Made of Special Sands and Mixes. G. Ziliani. (Metallurgia Italiana, 1951, vol. 43, June, pp. 216–220). Because of the recent increase in the use of special sands in place of bricks for ladle linings for basic steels, tests were

carried out to determine the best sands, their workability and their behaviour when in contact with molten steel and slag. Special attention is drawn to the importance of very careful preparation of the linings.—M. D. J. B.

Carbon Block for Open Hearth Bottoms. (Steel, 1951, vol. 128, Feb. 12, pp. 82–84). A suggested scheme for the use of carbon blocks 15 × 28 in. in section and 12 to 18 ft. long is put forward for use in the open-hearth furnace. Staggered joints are used for extra protection, they are set on a layer of insulation and covered by conventional cold-rammed magnesite to form the normal contour of the hearth.—A. M. F.

Refractory Concrete in Gasworks. A. E. Williams. (Gas Times, 1951, vol. 68, July 13, pp. 24, 27–29). For the construction and repair of furnaces, ovens, and flues, refractory concrete is in many ways superior to other types of refractory. It possesses a high degree of refractoriness, low conductivity, great strength and hardness, and is ready for use 24 hr. after placing in position. This type of concrete is a mixture of coarse and fine aggregates, (such as crushed firebrick), aluminous cement, and water. Normal grades are stable at temperatures up to 1300° C., and by incorporating special types of aggregate (such as chrome, magnesia, or fused alumina), temperatures up to 1770° C. may be withstood. Full details are given of preparation, special applications, and physical properties.—P. M. C.

Refractory Concrete: Some Industrial Applications in Furnace Construction. A. E. Williams. (Iron and Steel, 1951, vol. 24, May, pp. 160–162). The author discusses some of the industrial applications of refractory concrete, particularly for furnace construction, and outlines some of the advantages obtained by its use. Compositions of mixtures used in its manufacture are given, and the effects of variation of the mixture on the hot-crushing strength, refractoriness under load, and thermal conductivity are considered.—G. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Production of Pig Iron and Cement in a Rotary Furnace by the Basset Process. K. Seidel. (Stahl und Eisen, 1951, vol. 71, May 24, pp. 580–581). The method, employed in Japan during the war to produce pig iron and cement clinker by roasting burnt pyrites, coke, and lime in a rotary furnace, is described. The burnt pyrites, coke, and lime, in the proportions 100 : 70 : 130, were ground and granulated or briquetted. The charge was then fed through an internally heated furnace under strongly oxidizing conditions in order to melt the iron produced. The iron was run from the outlet of the furnace and the clinker was ground and freed from iron granules by sifting or magnetic separation. The necessary modifications to a Portland cement furnace are described.—J. P.

Assessment of the Design and Size of Hot Blast Stoves. W. Heiligenstaedt. (Stahl und Eisen, 1951, vol. 71, May 24, pp. 568–575). The choice of the design of the checkerwork is critical for the efficiency of a blast stove. The thickness of bricks used in modern stoves is generally so small that the utilization coefficient of the bricks approaches 100% and the influence of heat-transfer processes is negligible and that of heat storage predominates. The shape of the channels is without effect on the thermal efficiency of the checkers. The controlling factors: Channel width, brick thickness, heating surface and weight per unit volume of checkerwork, and free space are all fixed when two of them are chosen. The most suitable checkerwork is that which has the greatest weight of brick per unit volume for the permissible pressure drop. A hot-blast stove used as a gas accumulator is discussed.—J. P.

Reduction of Ferrous Oxide. O. H. Gellner and F. D. Richardson. (Nature, 1951, vol. 168, July 7, pp. 23–24). Polycrystalline wüstite layers prepared on strips of Swedish iron (total impurities 0·3%) have been reduced with hydrogen between 600° and 1000° C. At 700° C. reduction proceeds normally but at 900° C. it takes place mainly at the oxide/base-iron interface. This is attributed to the lowered stability of the oxide in contact with iron.—A. G.

A Study of Blast Pressures in Blast Furnaces. Part I—Experimental Study of Influencing Factors. P. Thierry, J. Szczeniowski, and J. Laborne. (Iron and Coal Trades Review, 1951, vol. 162, May 25, pp. 1199–1204). **Experimental Study of Factors Influencing Blowing Pressure in the Blast-Furnace.** P. Thierry, J. Szczeniowski, and J. Laborne. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 187–193). Of the factors (1) wind rate, (2) blowing section, (3) permeability of the charge, (4) blast temperature, and (5) top pressure, (2), (3), and (4) may be grouped as a term a, (the permeability of the blast-furnace) in the equation $p = p_0\sqrt{1 + a/p_0^2.G^2}$ where p is the blast pressure, p_0 the top pressure and G the wind rate. With no top pressure the equation becomes $p = \sqrt{1 + aG^2}$ and this has been verified by keeping a constant. a increases sharply as the blowing section is reduced, but provided blowing engines are adequate, smaller blowing sections give greater regularity of working.—A. G.

A Study of Blast Pressures in Blast Furnaces. Part II—Relation between Wind Volume and Pressure. P. Thierry, J. Szczeniowski, and J. Laborne. (Iron and Coal Trades Review, 1951, vol. 162, May 25, pp. 1204–1205). **Wind-Rate/Pressure Relationship in the Blast-Furnace.** J. Szczeniowski. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 296–298). In the equation $p = p_0\sqrt{1 + a/p_0^2.G^2}$ (where p = blast pressure, p_0 = top pressure, and G the wind rate) the coefficient of resistance a depends on the obstacles to gas flow, temperature, height of the blast-furnace, and the formation of gas. These factors are considered and data from Cleveland and Youngstown furnaces working with top pressure conform to the equation. Provided a is determined by observation the formula gives the rate-pressure curve.—A. G.

The Metallurgy of Metallothermic Smelting. W. Dautzenberg. (Zeitschrift für Erzbergbau und Metallhüttenwesen, 1950, vol. 3, Oct., pp. 341–347). The author discusses the principles involved in metallothermic processes, some using aluminium and others requiring other metals or alloys. The chemical reactions and physical factors involved and furnace design are dealt with.—O. H. G.

Statistical Study of Some Factors in Relation to the Composition of Iron from the Blast-Furnace. P. Rocquet and C. G. Thibaut. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 303–313). From data from five blast-furnaces significant positive correlations were found between iron temperature and the contents of sulphur, silicon, and manganese in the iron, but basicity appears to be independent of iron temperature. Curves expressing the percentage of one element in relation to another have the form $A^{\alpha}B^{\beta}$ = constant (*e.g.*, $S.Si = K$ and $S^2Mn^3 = K$). Significant negative correlations were found between the sulphur in the iron and slag basicity, and between the sulphur in the iron and the manganese in the slag.—A. G.

Thermodynamics of Iron-Silicate Slags: Slags Saturated with Gamma Iron. R. Schuhmann, jun., and P. J. Ensio. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, May, pp. 401–411; Journal of Metals, 1951, May). The oxygen activities of liquid iron-silicate slags in equilibrium with γ-iron have been determined at temperatures of 1250–1400° C. and over the composition range 0–40% SiO_2 (saturation). The experiments consisted of bubbling CO_2–CO mixtures through the slags in iron crucibles and determining the equilibrium ratio of CO_2 to CO. The results were consistent with those of other investigators. The activity–composition relationships deviated considerably from those expected for an ideal binary solution of FeO and SiO_2. The partial molal heats of solution of FeO from the melt in equilibrium with solid iron into the slag, and of liquid silica into silica-saturated slags, are both estimated to be zero.—G. F.

Quenching and Digging Out a Blast Furnace. K. C. McCutcheon, W. E. Marshall, and H. C. Barnes. (Journal of Metals, 1951, vol. 3, Apr., pp. 304–310). This article reports the results observed after the completion of the production run of a small blast-furnace at the Mines Experiment Station, University of Minnesota. After the production run, wire baskets containing various iron-bearing materials were charged at intervals for the purpose of studying the reducibility of the materials, the furnace then being tapped dry, cooled in an atmosphere of nitrogen, and dug out from the top down. The condition of the charge at different levels is described and illustrated. It is indicated that in this furnace the slag is made in the hearth from some of the lime, gangue from the melting ore, and ash from the coke, there being no evidence of the usual conception of a bosh slag made up from all the lime and all the gangue.—G. F.

Structure of the Yellow Crystalline Fraction of Blast-Furnace Salamander. J. R. Weeks, D. McLachlan, jun., and J. R. Lewis. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, May, pp.

393–394 ; Journal of Metals, 1951, May). The authors present the results of an X-ray study of the structure of a typical sample of the hard, infusible, yellow, cubic crystals often found on the lining and the hearth of the iron blast-furnace. The results indicate strongly that the crystals are primarily a solid solution of 1 part of titanium carbide to 4·7 parts of titanium nitride, with some substitution of vanadium for titanium. No evidence has been found of the complex titanium cyano-nitride originally reported by Wohler.—G. F.

TREATMENT AND USE OF SLAGS

The Importance and Origin of the Element Fluorine in Basic-Bessemer Slag. S. Gericke and B. Kurmies. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 454–457). The fluoride content of basic-Bessemer slag originates solely in the additions of ore, lime, and slag made to the converter. The usual fluoride content is insufficient to influence the solubility of the phosphate in citric acid or to have a deleterious effect on animals grazing over ground treated with the slag. High silica and low fluoride contents result in maximum phosphate solution rate.—J. P.

Economic Uses for Metallurgical Slags. L. Bor. (Mining Magazine, 1951, vol. 84, Feb., pp. 84–86). Uses for various types of metallurgical slag are surveyed and summarized. Mechanical applications include road metal, aggregates, ballast, filter beds, foundations, and in place of gravel or crushed stone. Slags are utilized chemically to produce cement, fertilizers, and slag wool, and for further metallurgical extraction.—E. C.

New Data on the Slag Minerals Nagelschmidtite and Steadite. E. R. Segnit. (Mineralogical Magazine, 1950, vol. 29, Sept., pp. 173–190). Nagelschmidtite and steadite are studied in various samples of basic slag. Textural associations of the minerals in the slags are described and details and data are given concerning their chemical compositions and optical properties. The system dicalcium-silicate/tricalcium-phosphate is discussed with special reference to slags and relationships are traced between nagelschmidtite and larnite.—E. C.

PRODUCTION OF STEEL

Alan Wood Steel Company. T. J. Ess. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 2A–18A). A detailed description is given of the development and expansion of the Alan Wood Steel Company. The works founded in 1857 now comprise coke ovens, blast-furnaces, open-hearth furnaces, a blooming mill, a plate mill, and a new 30-in. hot strip mill which came into operation in 1950.—M. D. J. B.

Italian Steel: Features of Some Northern Works. J. M. Butler. (Iron and Steel, 1951, vol. 24, May, pp. 163–167). The author briefly describes the general production methods and some of the more interesting features of the following North Italian steel plants: 'Cogne,' Aosta; 'Fiat,' Turin; 'Falch,' Milan; 'Breda,' Milan; and 'Dalmine,' near Bergamo. General comments on the Italian iron and steel industry are given.—G. F.

Quality Control in the Steelworks by Statistical Analysis. K. Daeves. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 430–433). The frequency distribution of the values of sulphur, phosphorus, and nitrogen in steel given by E. Maurer for East German works and of chromium and copper in American electric steel scrap is log-normal and therefore suitable for quality control. The nitrogen content of basic-Bessemer steel shows a log-normal mixed distribution which indicates that maintaining definite temperature and blowing conditions will permit the continuous production of low-nitrogen steel. This type of statistical and frequency analysis is advantageously applied to continuous quality control in steelmaking and to compare two steelworks.—J. P.

Present Status of Multiple Burners. L. D. Woodworth. (American Institute of Mining and Metallurgical Engineers, Open Hearth Proceedings, 1950, vol. 33, pp. 283–286). Double burners have helped to improve furnace performance at the Ohio works of the Carnegie-Illinois Steel Corp. and have permitted an extension of furnace campaigns concurrent with higher production and lower fuel rates.—F. C.

Manufacture of Basic-Bessemer Steel with Low Nitrogen and Phosphorus Contents: Review of Recent Developments. (Iron and Coal Trades Review, 1951, vol. 162, June 15, pp. 1377–1381). A review is given of recent developments in the production of low-phosphorus, low-nitrogen basic-Bessemer steel, which has similar ageing characteristics to those of open-hearth steels. The work of Dickie is first discussed, and the new converter practice at Corby is described. In this practice nitrogen absorption is reduced by use of a shallower bath, which decreases the partial pressure of the nitrogen in the blast and its time of contact with the molten bath, and by temperature control by means of millscale additions. The results of French and German trials are then given. In these trials, the charges were blown with oxygen-enriched air or mixtures of oxygen-enriched air with steam or CO_2. Analyses showing the reduction in nitrogen and phosphorus contents in each practice are given.—G. F.

Study of Some Properties of Basic-Bessemer Iron and of Its Aptitude to Dissolve Steel. M. Moray. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 194–198). Iron temperatures were measured by a sheathed platinum/platinum-rhodium thermocouple at different stages between tapping and charging to the converter. Fluidity, fusion temperatures, and the capacity to dissolve steel were also determined. High iron temperatures proved very beneficial in the steelworks.—A. G.

New Refractory Hung Arch Reduces Furnace Failures. (Journal of Metals, 1951, vol. 191, Feb., p. 96). A brief description is given of a new type of pendulum-hung suspended refractory arch which is claimed to reduce furnace roof failures. The arch is flexible and can be attached to the existing steel framework of most furnaces with little structural change.—G. F.

Changes in Roof Design and Elevation and Their Effect on Roof Life. R. P. Carpenter. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 87–88). A new method of cooling the skewback channels of an open-hearth furnace at the Corrigan McKinney plant of the Republic Steel Corporation and the consequent raising of the roof by 6 in. rendered necessary by this mode of cooling has resulted in less damage to the skewback channels. Roof life and furnace availability have increased whilst there has been no increase in the thermal input to the furnace or in heat time.—F. C.

Brick in Basic-End Furnaces. E. R. Westfall. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, p. 221). Port-roofs and uptakes constructed in burned brick have been shown to have a longer life and to require less patching than those made of unburned brick.—F. C.

Progress Report on All-basic Furnace at South Works, Carnegie-Illinois Steel Corporation. M. F. Yarotsky. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 217–218). In four campaigns over three years an all-basic furnace has not proved economically advantageous over the conventional silica furnace. Fuel rates are 10% above the average for the rest of the shop, production 11% greater and cost 4% greater. Unfired steel-encased chrome-magnesia brick is preferred in the main roof and there is no clear-cut difference between several brands of chrome-magnesite refractories in the port-roof and end walls. Bottom delays are greater than with a normal furnace whilst the as-rolled surface quality of the steel produced is slightly better. Proposed modifications to construction and fuel system are given.—F. C.

Progress Report on All-Basic Furnace at Steel Company of Canada. A. K. Moore. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 219–220). After six campaigns it is considered that further work with a basic roof will depend on the prospect of obtaining a longer roof life and lower fuel costs.—F. C.

Comparison of Burned and Unburned Brick in Basic Ends. R. C. Solomon. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 222–223). Although information is limited there is a tendency to favour burned brick for the construction of port-roofs and burner arches.—F. C.

Charging Practice: Its Effect on Open-Hearth Output. W. Schwinn. (Journal of Metals, 1950, vol. 188, Sept., p. 1089). The author briefly discusses the open-hearth charging practice at the Keystone Steel and Wire Co., Peoria, Illinois, and describes the effect of variations in the charge on the steel output.—G. F.

Thermal Analysis of Open-Hearth Furnace Operation. A. Benda. (Iron and Steel Institute, 1951, Translation Series, No. 423). This is an English translation of a paper which appeared in Hutnické Listy, 1950, vol. 5, Nov., pp.

454–457 (*see* Journ. I. and S.I., 1951, vol. 168, June, p. 189).

Combustion in the Open-Hearth Furnace. J. M. Brashear. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1951, vol. 39, Apr., pp. 421–425, 476). The author discusses the control of some of the variables which influence heat transfer in the open-hearth furnace. The rate of burning fuel is dealt with and the results of experiments on the direction and location of the air stream entering the hearth or combustion area are discussed. Constant furnace pressures were not desirable or conducive to the most efficient operation of the furnace. An investigation of the influence on flame temperature and radiant characteristics of the flame by varying steam temperatures, pressures and volumes, liquid fuel temperatures, pressures and viscosities indicated that the temperature and volume of steam rather than the pressure are important.—J. P. S.

Distribution of Sulphur between Liquid Iron and Slags of Low Iron-Oxide Concentrations. R. Rocca, N. J. Grant, and J. Chipman. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, pp. 319–326; Journal of Metals, 1951, Apr.). This article describes an investigation of the influence of basicity and FeO content of slags on sulphur distribution between molten iron and reducing slags of the electric furnace type, data from 65 heats being studied. It is concluded that, for all FeO concentrations, desulphurization can be explained on the basis of the following reactions:

(1) $[FeS] \rightleftharpoons (FeS)$
(2) $(FeS) + (CaO) \rightleftharpoons (CaS) + (FeO)$
(3) $[FeS] + (CaO) \rightleftharpoons (CaS) + (FeO)$.

In highly reducing slags, reaction (2) is the controlling factor, reaction (1) becoming more important as the FeO content of the slag increases. Increasing amounts of excess CaO in the slag also increase the desulphurization ratio.—G. F.

The Open-Hearth Furnace in Italy. E. Bolsi. (Metallurgia Italiana, 1951, vol. 43, May, pp. 190–192). The author gives a brief description of open-hearth practice in Italy. Reference is made to the economics of cold and hot metal shops, hourly production, coal consumption, wear in refractory bricks, and the uses of magnesite, silica, and chromite for furnace linings.—M. D. J. B.

Deoxidation of Steel by Acid Synthetic Slags: German Research on Slag–Steel Reactions. (Iron and Coal Trades Review, 1951, vol. 162, Apr. 20, pp. 919–922). This paper reports the investigation by M. Paschke and G. Gesche (*see* Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 5–8 and Journ. I. and S.I., 1951, vol. 168, Aug., p. 418).

Effect of Hot Metal on Open Hearth Production. W. A. Greene. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 13–23). The selection and analysis of 1105 heats with 0·13 to 0·30% ladle carbon and 0·035 to 0·045% S from a total of 4662 heats produced at the Fontana Works during 1949 together with a statistical analysis of 110 of the above 1105 heats led the author to conclude that: (1) The presence of manganese in hot metal is not essential for efficient sulphur removal in the open-hearth process as estimated in terms of the rate of production. (2) The use of additional manganese in the blast-furnace burden does not assist the removal of sulphur in the blast-furnace process. (3) Higher silicon in the hot metal is beneficial to the rate of production in scrap heats and detrimental in ore heats. (4) Higher phosphorus in the hot metal decreases the yield and increases the lime consumed, the time of the heat, and the percentage of sulphur at melt. (5) Higher sulphur in the hot metal causes a decrease in production. (6) The rate of production increases with increasing percentage of hot metal charged (within the range 25–60%) in spite of a corresponding decrease in yield.—F. C.

Factors Affecting Surface Quality of Plain Carbon, Fully Killed Open-Hearth Steels. R. L. Roshong and G. P. Michalos. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 25–33). This paper describes a statistical analysis of the factors affecting the surface quality of blooms. The data were derived from heats selected from 200 heats made in three 120-ton open-hearth furnaces. The surface quality improved when the manganese content lay between 0·40 and 0·60%, with decreasing content of total nickel plus copper, particularly below 0·25%, and with a decreasing silicon content below 0·15%. The poorest surface quality was obtained at 0·10% C, the quality improving on either side of this figure. Both cold heats and a sulphur content in excess of 0·027% have a detrimental effect.—F. C.

Progress Report on the Use of Metallurgical Oxygen. P. W. Nutting. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 51–59). Replies to a questionnaire submitted by 20 steel plants show that oxygen is now used extensively throughout the steel industry, principally for decarburizing. Oxygen consumption for this practice averages 89 cu. ft./ton with a resultant fuel saving of 176,000 B.Th.U. per ton and an increased production of 0·45 tons/hr. on a charge-to-tap basis. Oxygen for flame enrichment is used only in cases where the demand for increased production offsets the increased costs and furnace wear. Consumption in this case is 325 cu. ft./hr. with an increase in production of 1·45 tons/hr. and a saving of 362,000 B.Th.U./ton in fuel. Opinion is unanimous that the use of oxygen for flame enrichment and decarbonization at high carbon levels causes damage to furnace refractories and that this damage may be reduced by careful operation.—F. C.

Faster Charging Practice. V. W. Jones. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 62–65). The No. 2. open-hearth shop of the Armco Steel Corporation, Middletown, Ohio, which is at present under construction, is designed so that there can be no interference caused by two furnaces charging at the same time. The main feature of the installation is the use of hydraulic hoists to raise scrap pans from yard level into charging position where they are then loaded by the conventional charging machines. The empty pans are returned to yard level by a further hoist at the other end of the furnace being charged. This method will permit the charging of a 225-ton heat of 70% scrap in 1½ hr.—F. C.

One Method of Handling Stool Stickers. R. Wolcott. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 68–70). This paper briefly describes methods of handling stool 'stickers' with particular reference to experience with carbon inserts. It outlines both the methods employed to prevent sticking and those employed when preventive measures have failed.—F. C.

A Few Factors Affecting Stool Stickers. C. G. McCabe. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 71–73). To prevent stool 'stickers' the initial temperature of the stool should be less than 100° F. and high teeming temperatures should be avoided. A composite stool used by the Wheeling Steel Corporation is described. The stool consists essentially of a cast-steel casing into which are fitted interchangeable cast-iron inserts.—F. C.

New Mold Coatings. J. J. Golden. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 77–80). An investigation into the comparative merits of three ingot-mould dressings, *viz.*, tar, Darmold, and Hydropaste has shown that the tar gives a slightly better surface quality with rail castings whilst Darmold is better for billet and slab products. Two types of sprayer are described. Darmold is a colloidal graphite mixture and Hydropaste a non-inflammable paste of flake aluminium and binder; the latter is mixed with water before application. Darmold may be used directly as supplied or diluted with water.—F. C.

Use of Refractory Throwing Guns. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 89–90). This is a short discussion on the various uses of the B.R.I. and Allentown refractory throwing guns in the maintenance of open-hearth furnaces.—F. C.

Substitutes for Pig Iron. G. S. Baldwin. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Poceedings, 1950, vol. 33, pp. 91–92). The use of natural gas coke (99·5% C, S max. 0·05%) for carburizing has shown a 4 to 5% better yield than other carburizing materials.—F. C.

Use of Graphite in the Cold-metal Charge. C. B. Jenni. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 93–95). Graphite has been used for well over 18 months and has been proved to be a reliable source of carbon in cold-metal charges.—F. C.

Quality of Raw Materials. G. McMillin and J. R. Patton. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 103–106). The authors consider the quality of burnt lime and fluorspar used in open-hearth operation based on data received from 59 cold-metal, non-integrated, basic open-hearth furnace plants.—F. C.

Storage and Distribution of Oxygen for the Open Hearth. B. P. Sarasin and R. Tietig, jun. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 81–89). Because oxygen is produced at a fairly constant rate whereas its consumption is highly variable, a correctly designed storage and distribution system for the gas is necessary. This paper discusses the design of a system which will result in the minimum operating cost including fixed charges. The following aspects of the problem are considered: Preliminary design data; demand for oxygen; method of producing oxygen; storage; compression units; piping; instrumentation and controls; safety; and other uses of oxygen. The authors discuss each of these items with reference to plant where the installation of an oxygen generating unit can be justified by increased ingot production and lower cost.—M. D. J. B.

Metallurgy of the Graphite-Rod Furnace. W. Gödecke. (Giesserei, 1951, vol. 38, Apr. 19, pp. 169–174). The author describes the use of thermomechanically stabilized dolomite in the graphite-rod melting furnace operated with highly basic slag. Data on the melting and refining processes obtained in a 30-kg. experimental furnace are given and attention is drawn to the possibility of decarburizing at 1900° C. ferritic and austenitic Cr–Ni steels high in chromium. A comparison between electric-arc and high-frequency furnaces shows that all slag operations which are possible in the former can also be performed in the latter.—J. G. W.

Electrodes for Arc Furnaces. Y. Dardel. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 205–218). A survey of the properties of carbon and graphite and the mechanism of graphitization is followed by a description of the process of manufacturing electrodes. The choice of type of electrode is governed by current density and economic considerations.—A. G.

The Electric Furnace in Italy. P. Raffo. (Associazione Italiana di Metallurgia: Metallurgia Italiana, 1951, vol. 43, June, pp. 241–244). After a brief review on the development of the electric furnace in Italy, operating details are given of the latest types of furnace used. Silica and sillimanite furnace roofs, furnace linings and port design are considered.—M. D. J. B.

West's Largest Electric Furnace Increases Steel Making Capacity at Bethlehem Pacific. (Western Metals, 1950, vol. 8, July, p. 19). Brief constructional details and photographs are given of the new 75-ton Moore Rapid Lectromelt steelmaking furnace, recently installed at the Los Angeles plant of the Bethlehem Pacific Steel Co. The furnace is 20 ft. in dia. and uses three electrodes 20 in. in dia.—P. M. C.

Advances in Stainless Steelmaking Practice. A. B. Scott. (Australian Institute of Metals: Australasian Engineer, 1951, Apr. 7, pp. 44–50). The author describes in detail the electric arc and induction furnace methods of stainless-steel production. Different techniques involving carbon steel scrap oxidation, stainless scrap oxidation, ore oxidation, and the recently developed oxygen lance process are all discussed, and typical process charts are reproduced for an actual heat of each type. Information on temperature measurement and casting-pit practice is also included.—P. M. C.

High-Frequency Furnaces for the Manufacture of Special Alloys at Grenoble. (Journal du Four Electrique, 1951, vol. 60, May–June, p. 65). Brief details are given of the installation and operation of high-frequency induction furnaces at the works of the Société d'Electro-Chimie, d'Electrométallurgie et des Aciéries Electrique d'Ugine.—B. G. B.

Measuring the Viscosity of Metallurgical Slags. M. D. E. Jonckers. (Métallurgie, 1951, vol. 83, Apr., pp. 235–240; May, pp. 341–349). Amongst the factors affecting the velocity of reactions between the gas–slag and the slag–metal interfaces are chemical equilibria which, in turn, depend on the duration and speed of refining, and the composition and viscosity of the slag. The author reviews work done on the correlation between temperature and fluidity and composition of slags. The Hanlein, Margules, and Heidtkamp viscosimeters are described. The theories of binary, ternary, and quaternary system slags are examined. Viscosity measurements on acid and basic blast-furnace slags and on basic-Bessemer dephosphorizing slags are described.—R. S.

Ingot Moulds: Practical Aspects of the Quasi-Bessemerizing Process. W. S. Williams. (Iron and Steel, 1951, vol. 24, Apr., pp. 113–114, 123). The author describes some of the practical aspects of the quasi-bessemerizing process and discusses its possible advantages in the manufacture of ingot moulds. Its effect on the mould base and on corner scale formation are considered, and it is suggested that mould cracking and crazing could be deferred by quasi-bessemerizing during manufacture. A tentative explanation of the mechanism of the process is included.—G. F.

Mechanical Properties of Ingot Mould Irons. J. W. Grant. (B.I.S.R.A. Symposium on Stresses in Moulds: Journal of The Iron and Steel Institute, 1951, vol. 168, July, pp. 263–273). Mechanical tests have been carried out on ingot mould irons at temperatures up to 800° C. to provide stress/strain data from which stresses in ingot moulds may be calculated, and to investigate the behaviour of these materials under the type of stress and strain conditions to which an ingot mould might be subjected during its life. Transverse, tensile, compression, creep, and 'endurance' tests were carried out. The weaker irons gave the greatest extensions for a given load, the magnitude of the extensions being greater at 400° C. than at room temperature, but there was no change in ultimate tensile stress. In the endurance tests at 400° C., failures occurred after less than 100 repeated applications of less than 80% of the ultimate tensile stress. During the life of an ingot mould, the outside surface reaches a temperature of over 600° C. before cooling and being re-used. When a test piece was permanently deformed by straining and was then subjected to the same temperature cycle, the same stress/strain curve as in the first test was obtained. There was evidence, however, of a damaging effect causing the iron ultimately to break at a lower stress and at a lower total elongation than if it had not been heat-treated in this manner.

Poisson's Ratio for Cast Iron Used for Ingot Moulds. J. Woolman. (B.I.S.R.A. Symposium on Stresses in Moulds: Journal of The Iron and Steel Institute, 1951, vol. 168, July, pp. 273–277). A lateral extensometer suitable for attaching to a test piece in a cylindrical electrical furnace has been designed and constructed. With this, in conjunction with a conventional type Lamb roller extensometer, Poisson's ratio determinations have been made on a number of ingot mould irons, both at room and elevated temperatures. The value of the Poisson's ratio is shown to vary with the stress, the temperature, and with repeated applications of the load, although with the latter the ratio tends to a constant value. A theory is put forward to account for the observed variation in the properties of the iron with graphite size. This postulates that some separation of the metal from the graphite flakes occurs when the irons are subjected to tensile stresses. Because of the variations in the observed values of Poisson's ratio it is difficult to suggest an appropriate value for use in calculations unless some knowledge of the tensile properties of the irons is available.

Growth Characteristics of Some Cast Irons Used for Ingot Moulds. W. C. Heselwood and F. B. Pickering. (B.I.S.R.A. Symposium on Stresses in Moulds: Journal of The Iron and Steel Institute, 1951, vol. 168, July, pp. 277–286). The work described originated in an attempt to devise a simple test which would assess the susceptibility to growth of different ingot-mould irons. Repeated heating and cooling tests were followed by determinations of the isothermal growth at different temperatures, and the measurement of growth occurring during 5 hr. at 700° C. under conditions of limited access of air (to minimize scaling) was finally adopted as an arbitrary test, and was applied to 16 irons of differing analyses. From the results, a tentative relationship has been obtained indicating the influence of Si, Mn, and P on susceptibility to growth. The mechanism of growth in cast irons is discussed, and a suggested mechanism is tested experimentally. Correlation of the test results with the lives of related ingot moulds is largely masked by other variables, but the possibility of a relationship is briefly discussed in an Appendix.

Note on Relaxation Test on Cast Iron. J. Woolman. (B.I.S.R.A. Symposium on Stresses in Moulds: Journal of The Iron and Steel Institute, 1951, vol. 168, July, p. 287). A sample of ingot-mould iron was loaded at 4 tons/sq. in. at 450° C. and the load then removed in such a manner that the length of the specimen remained constant. The stress relaxed quickly at first but did not reach constant values even after

19 hr. This and another test at 700° C. indicated that it is improbable that growth can have any influence on the stresses induced in an ingot mould during use.—R. A. R.

Determination of Surface Stresses in Ingot Moulds. M. W. Buttler and W. H. Glaisher. (B.I.S.R.A. Symposium on Stresses in Moulds : Journal of The Iron and Steel Institute, 1951, vol. 168, July, pp. 287–299). When a cast-iron ingot mould is filled with molten steel, stresses are produced in the walls owing to the steep temperature gradients set up. By measuring the consequent strains, it is possible to evaluate these stresses, if certain properties of the mould iron are known. The results of such tests are given and the possibilities of the stress causing failure of the mould by cracking are discussed. The temperature cycle at various points in a mould, and the effect of heat-treatments designed (*a*) to promote growth of the mould iron, and (*b*) to determine the extent of residual stresses in the mould when cold, have been examined.

Statistical Methods in the Study of Ingot Mould Usage. N. H. Bacon. (Journal of the West of Scotland Iron and Steel Institute, 1945–46, vol. 53, pp. 102–119). The author states, after listing the factors affecting mould life, that the only approach to the problem likely to be successful is a statistical one, a prerequisite of which is the careful recording of the relevant data. A suitable mould history card is described on which are entered data relative to the manufacture of the mould, and details connected with its use. After analysing statistically some of the data it is concluded that: (*a*) Within certain limits mould life increases with decreasing silicon content, other things being equal, and (*b*) a minimum period of 15 hr. should elapse between use if the maximum possible life is to be obtained. The scatter diagrams and the method of obtaining the correlation coefficient *r* for this analysis are given. Using this information the mould life was increased in practice from 80 to 130 casts. The effect of a shorter stripping time is shown by a control chart. This chart and its method of construction are described. From a partial correlation it is concluded that stripping time is more important than interval between casts with regard to mould life. The effects of silicon content and casting-pit treatment as regards stripping times, and of mould usage intervals are of about equal importance. An example is given of the application of the statistical test known as ' student's *t*.'—P. C. P.

Jet Tapping. H. Walker and A. R. Almeida. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, 1951 : Journal of Metals, 1951, vol. 3, May, pp. 374–376). This article describes the construction, operation, and development of the ' Jet Tapper,' a directional explosive charge for opening furnace tap-holes. It is claimed to give a clean fast tap without heavy labour and with greater safety, enabling additions to be made under the best conditions, and resulting in reduced skulling, less manganese loss, and better tap-hole maintenance. Figures showing the reduction in skulling are provided, based on a comparison of the new method with the oxygen-lance method of opening tap holes.—G. F.

Safety Precautions in Jet Tapping. R. H. Ferguson. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference, 1951 : Journal of Metals, 1951, vol. 3, May, pp. 377–378). Safety precautions necessary in the use of the ' Jet Tapper ' and the rules laid down for the operating procedure are discussed. Several experiments carried out during its development are also described.—G. F.

A.I.S.E. Specification for Design of Hot Metal Ladles. I. E. Madsen. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 119–122). This paper describes research at the Fritz Engineering Laboratory of Lehigh University on the stress analysis of hot metal ladles. A ' hot metal ladle committee ' was appointed to simplify the original report and put it on a more practical basis. The principal points of the committee's work are summarized and tables of stresses determined by the proposed design method when applied to full-sized ladles and test ladles are given.—M. D. J. B.

Observations on Rimming Steel Ingots. A. Hultgren, G. Phragmen, S. Wohlfahrt, and J. E. Ostberg. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 191, pp. 101–110 ; Journal of Metals, 1951, Feb.). The authors present the results of a number of experiments carried out on rimming steel ingots. The main investigation is concerned with the effects of superimposed air pressure on the solidification process and the resulting structure of 12 in. sq. ingots of 0·12% C, 0·48% Mn steel, some of the moulds having a refractory insert at the top. An additional air pressure of 10–15 atm. is sufficient to prevent all gas evolution, and the ingot solidifies in the manner of a killed steel. A pressure of 6½ atm. results in a semi-killed ingot, and 3–5 atm. produces a rising ingot. The sectioned ingots are illustrated and the probable mechanism of freezing under the various conditions is discussed. A second investigation concerned rimming ingots with about 0·4% C, and it is shown that with such steels a good rimming action is more difficult, but not impossible to produce. The inner part of the rim zone tends to develop a globular freezing structure, and the number of blowholes in the outer rim zone increases on rapid casting. A study of the distribution of the large round non-metallic inclusions found in rimming ingots, consisting of (Fe, Mn)O and sulphide in a silicate matrix, is then described. The inclusions occur to the greatest extent in the lower part of the core. Finally, the authors describe experiments to determine the extent of continuity in the ' rim channels,' or long narrow, roughly horizontal pores often found in the upper part of normal rimming ingots. In the cases investigated, these channels were discontinuous to a depth of 1¼ in. from the surface, but continuity is shown from this depth to the intermediate blowhole zone.—G. F.

A Review of Current Practice and Possible Improvements in Ingot Feeder Heads. H. O. Howson. (Iron and Coal Trades Review, 1951, vol. 162, Apr. 20, pp. 901–913). The author reviews current ingot feeder-head practice and discusses possible improvements. The intrinsic efficiency of refractories is considered and it is shown that the important criterion is inherent thermal capacity, conductivity being subsidiary. Special mention is made of the possibilities of a new design of refractory tile in which the face remote from the steel is recessed and either filled with insulating material or left as an air-gap. The practical design of hot-tops is next considered, and the author considers that the integral type offers the greatest advance. Finally, the insulation of the upper surface, and the application of exterior heat to the feeder head, are discussed.—G. F.

FOUNDRY PRACTICE

Foundry Research in the World's Main Industrial Countries. (Giesserei, 1951, vol. 38, June 28, pp. 293–299). Foundry research in France, U.S.A., Great Britain, Spain, and Germany is reviewed. Details are given of the principal research centres in each country, their organization, contacts with industry, and means of publishing completed work.—J. G. W.

Circulation of Iron in the Foundry. C-G. Nilsson. (Gjuteriet, 1950, vol. 40, Apr., pp. 47–49). [In Swedish]. The advantages of employing a monthly Sankey diagram for evaluation of the iron circulation within the foundry are pointed out.—B. S. E.

Contribution to the Measurement and Improvement in the Use of Load and Power in the Foundry. V. Unger. (Giesserei, 1951, vol. 38, June 28, pp. 299–304). Foundry work is analysed from the point of view of materials handling. Data relating to quantities and distances over which the materials are moved show that 160 tons of materials have to be lifted for every ton of malleable iron castings and 1563 tonne-metres work is involved in the transporting and handling of the materials. Suggestions for improvement are made on the basis of experience in one foundry.—J. G. W.

Annual Meeting of the Czech Foundrymen Association and the Great Task Ahead. (Hutnické Listy, 1951, vol. 6, Apr., pp. 157–158). [In Czech]. The achievements and future tasks of the Czech foundry industry are dealt with. Some success has been obtained in the use of nodular cast iron on a larger scale, but it has not been possible to shorten the production times of malleable iron castings. The percentage of malleable castings used in Czechoslovakia is very low. The production of steel castings in 1950 was 34% higher than in 1949. Not enough is being done to train personnel and exchange experience.—E. G.

Continuous Billet Casting : Application to High-Melting-Point Alloys. J. C. Wright. (Birmingham Metallurgical Society : Iron and Coal Trades Review, 1951, vol. 162, June 8, pp. 1319–1323). The author discusses some of the technical difficulties involved in producing continuously cast billets of high-melting-point alloys. Particular attention is given to

the problems associated with the low thermal diffusivity and high heat content of the alloys and the high pouring temperatures required, and some of the methods employed to overcome these difficulties are discussed. The machines suitable for high-melting-point alloys are then considered, a description of the Babcock and Wilcox commercial plant being included. Finally, the economic aspects of continuous casting are discussed.—G. F.

The Indirect Three-Phase Arc Furnace "Péchiney-Cartoux" in the Iron Foundry. (Journal du Four Electrique, 1951, vol. 60, Mar.–Apr., pp. 45–47). Details are given of trials carried out with this type of furnace in order to ascertain its possibilities for iron foundries. The results have shown that the furnace by virtue of its design is eminently suitable for the easy and controlled melting of metals for casting.—B. G. B.

Refrigeration Controls Blast Moisture. W. K. Mitchell. (Foundry, 1951, vol. 79, Apr., pp. 134–137). The use of a refrigeration plant to control the humidity of air fed to a cupola is described. Grey iron castings had been scrapped because of porosity and it was thought that hydrogen was being introduced into the metal from the cupola blast. It was found that scrap percentage was related to humidity and that moisture removal by refrigeration reduced this loss from about 15% to 7%. On a summer day as much as 9 lb. water/min. were removed from the cupola blast.—E. J. D. S.

Composition and Utilization of Stack Gases in a Small Cupola. W. Chrétien-Horand. (Giesserei, 1951, vol. 38, June 14, pp. 275–276). It was found that conditions in a small cupola with a melting zone 600 mm. dia. were appreciably different from those encountered in large cupolas. Gases free from or low in carbon monoxide were found at high temperatures. It was also confirmed during two years' work with a small cupola that it is possible to reduce the oxidizing action of stack gases and utilize their heat content.—J. G. W.

Production Experience and Its Application to the Hot-Blast Cupola. O. Mattern. (Giesserei, 1951, vol. 38, June 14, pp. 269–273). Experiments were performed in a hot-blast cupola 800 mm. in inside dia. The results are discussed with reference to the conversion of cupolas from cold to hot blast.—J. G. W.

Slag Reactions in the Cupola. E. Witten. (Giesserei, 1951, vol. 38, May 17, pp. 221–227). The author concludes from published data and his own research that cupola furnace slags take up certain fixed proportions of iron and manganese, which are determined by the melting point of the CaO–SiO_2–Al_2O_3 mixture, the ratio of lime to silica, and the temperature. Desulphurization is directly associated with the slag basicity and the melting point of the lime–silica mixture. This melting point is strongly influenced by the alumina content. The carbon and silicon content of the molten iron increases up to the 'neutral' as the sum $(\Sigma Fe) + (\Sigma Mn)$ falls. This opens up the possibility of reducing pig additions. With regard to the action of fluorite, the author suggests that the evidence, though not entirely conclusive, points to the inadvisability of the use of fluorite when sulphur loss from the cupola is negligible. Recommendations are given for the best composition of the lining.—J. G. W.

Basic Cupola Melting and Its Possibilities. E. S. Renshaw. (American Foundrymen's Society, 1951, Preprint No. 41). The use of a basic-lined cupola as part of a production unit is described, and experience gained in operating with basic slags is discussed. Slag conditions which favour desulphurization to low limits also give high carbon pick-up in low-carbon charges and the possibility of taking advantage of these factors is discussed with particular reference to nodular iron production. Additional refractory cost may prove to be justified if subsequent processing cost is lowered by reducing the quantity of alloy required for ladle treatment. Reference is made to water cooling as a means of reducing refractory erosion and offering the possibility of operating with slags of higher basicity.—P. C. P.

Desulphurizing Molten Iron with Calcium Carbide. S. D. Baumer and P. M. Hulme. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, pp. 313–318; Journal of Metals, 1951, Apr.). This article describes experiments using calcium carbide to desulphurize molten iron, both on a laboratory scale and on a pilot-plant scale, in which carbide was fed continuously into a forehearth installed at the cupola. The results show that calcium carbide will consistently remove more than 90% of the sulphur in the iron, sulphur contents of 0·01–0·02% being attained, and there is no reversion of sulphur from slag to iron. The efficiency is independent of sulphur content and temperature, but the process is more expensive than using soda ash and is not competitive when sulphur contents of 0·06–0·08% are satisfactory in the treated iron.—G. F.

Casting Long and Wide Pipes. F. O. Nordbeck. (Gjuteriet, 1950, vol. 40, Dec., pp. 208–210). [In Swedish]. The technique for casting pipes weighing 4–6 tons in lengths of 4–6·5 m. is characterized by a vertical flask containing a clay-coated steel spindle through which air circulation is maintained. The flask is placed on a steel plate in a pit.—B. S. E.

Material Characteristics and Constructional Rules for Grey Iron Castings. H. Hugo and C. W. Pfannenschmidt. (Giesserei, 1951, Special Issue 'Konstrukteur und Giesser,' pp. 7–20). The paper contains, in addition to data on material characteristics, numerous design examples which illustrate requirements of sound and economic moulding and casting. Notch insensitivity, and resistance to abrasion and corrosion are pointed out as advantages of grey-iron castings, and attention is drawn to good machinability, and scope for surface hardening and welding. The factors having the greatest influence on design are contraction, withdrawal of patterns, and cleaning of castings.—J. G. W.

Some Effects of Temperature and Melting Variables on Chemical Composition and Structure of Gray Irons. E. A. Lange and R. W. Heine. (American Foundrymen's Society, 1951, Preprint No. 47). This paper presents results of a study of melting phenomena that direct the course of composition and structural changes in grey cast iron. Variables studied affecting chemical composition were air oxidation of the iron in various refractories, the effect of temperature on composition changes, influence of slags, iron oxide, rusty soap, coke, and the results of melting under a CO atmosphere. Silicon oxidation was promoted at low temperatures and prevented at high temperatures by oxidizing atmospheres. Carbon losses were practically nil at low temperatures and increased rapidly with temperature. Silica reduction was normal chemical reaction in molten cast iron at temperatures above 2670° F. The effects of iron oxide in causing oxidation were entirely different from atmospheric oxidation. Structural changes were related to oxidizing melting conditions with chilling tendencies being promoted but dependent on temperature. The principles of temperature-dependent chemical reactions causing composition and structural changes are discussed.—P. C. P.

Contribution to the Manufacture of Ingot Moulds. E. Feil. (Giesserei, 1951, vol. 38, July 26, pp. 345–355). The author has investigated the causes of premature failure of moulds by cracking, both on moulds and on the 95-mm. dia. sprues. He concludes that for optimum life the graphite should not be too finely divided, the ratio of the surface hardness to that about 5 mm. from the surface should be between 0·95 and 1·00. Sulphur segregation is injurious. Other factors are nature of the mould skin, grain size in the interior, and constitution of charge. The author stresses that pig iron specially produced for the purpose is the most important condition for attaining a uniformly high mould life.—J. G. W.

Ductile Cast Iron. P. Markwell. (Australian Institute of Metals: Australasian Engineer, 1951, Mar. 7, pp. 61–65). After a brief review of the relative merits of the terms 'nodular,' 'spheroidal,' 'spherulitic,' as applied to the new types of ductile cast iron, the author discusses in some detail the factors governing graphite formation. The use of the nodularizing agents Mg–Cu, Mg–Ni, cerium, and Si–Mg–Ca is described, and the basic-lined cupola melting process is outlined. The calculation of structural composition from a knowledge of the chemical constituents as well as the marketing possibilities and engineering applications are discussed.—P. M. C.

Deoxidation in Production of Nodular Cast Iron. G. Derge. (Foundry, 1951, vol. 79, Apr., pp. 122–123). Exeriments are described which showed that the magnesium treatment resulting in nodular graphite formation in cast iron is also responsible for deoxidation. Furthermore, these conditions were associated with a definite residual alloy content of magnesium and aluminium. It is not known whether nodular graphite results directly from the low oxygen level without reference to the procedure used, or from some indirect effect of deoxidation such as the formation of magnesium sulphide nuclei.—E. J. D. S.

Spherulite Formation in Nodular Cast Iron. A. L. De Sy. (Metal Progress, 1951, vol. 59, June, pp. 798–800). Research

suggests that there is probably only one mechanism of formation of graphite spherulites, although the nature of this mechanism is not known. Their formation can result from the addition of minute quantities of strong deoxidizers like magnesium, cerium, lithium, barium, calcium, or strontium. The soldification of as-cast nodular magnesium-treated iron corresponds to undercooling without recalescence.—E. T. L.

Nodular Graphite Cast Irons. L. Nava. (Metallurgia Italiana, 1951, vol. 43, June, pp. 221–240). The manufacture of nodular graphite cast irons presents no serious difficulties and can be carried out in any well-equipped foundry possessing the necessary control apparatus. A detailed description is given of the general conditions essential for making these castings. Detailed consideration is given to the magnesium method of producing these irons, and their characteristics with and without heat-treatment are discussed. Considerable technical and statistical data are given together with a comprehensive bibliography.—M. D. J. B.

New Experiences with Nodular Cast Iron. O. Carlsson. (Gjuteriet, 1950, vol. 40, Mar., pp. 31–37). [In Swedish]. This report covers experiments with additions of magnesium alloyed with copper (80%) and with nickel (75%). Charcoal pig iron gave strength values of 50 kg./sq. mm. when containing 0·05–0·1% Mg, which meant a loss of 60–80% of the added magnesium. A melt of charcoal pig iron and steel scrap given a sulphur content of 0·035% by adding FeS and containing varying amounts of manganese was treated with Ni–Mg before inoculation with ferrosilicon to raise the silicon content 1%. Cast test pieces gave tensile strength well above 50 kg./sq. mm. The shrinkage is pointed out to be greater than that occurring in ordinary cast iron, and the costs are said to be comparable with those of annealed castings.—B. S. E.

On the Crystallization of Nodular Graphite. L. Gillemot. (Öntöde, 1951, vol. 2, Mar., pp. 49–56; Kohászati Lapok, 1951, vol. 6, Mar.). [In Hungarian]. Experiments were carried out to study the influence of the carbon, silicon, and cerium contents, the wall thickness, and the temperature on the formation of nodular graphite in iron castings. The pouring temperature was kept at 1480° C. except when this factor was the subject of study. The results showed that nodular graphite in a ferrite–pearlite matrix can form only in a limited range of silicon and cerium contents; it is possible to obtain nodular graphite in a matrix of ferrite or pearlite plus carbide outside this silicon and cerium range. Contrary to Myskowsky and Dunphy, this author found that formation of nodular graphite depends greatly on the carbon content. The influence of remelting and heat-treatment was also investigated. The author believes nodular graphite is formed by the decomposition of undercooled carbide.

High-Strength Castings. L. Frank. (Öntöde, 1951, vol. 2, Feb., pp. 25–30: Kohászati Lapok, 1951, vol. 6, Feb.). [In Hungarian]. Developments in the production of high-grade cast irons are reviewed and their use in several countries is discussed. Consumption of malleable iron at the Stalingrad Tractor Works has decreased 90% since inoculated cast iron was introduced in 1948; details of the production process are given. Acicular cast iron is used to produce cast crankshafts for 40-h.p. diesel engines. There are insufficient heat-treatment furnaces in Hungary for making malleable iron castings. The heat-treatment time can be reduced to 12–17 hr. by using a very low silicon iron and making silicon–magnesium additions. An iron which can be rolled can be made by adding silicon–magnesium alloy to liquid iron very low in sulphur, phosphorus, and manganese.

Contribution to Rules for the Design of Malleable Iron Castings. F. Roll. (Giesserei, 1951, Special Issue 'Konstrukteur und Giesser,' pp. 53–63). Applications of high-quality white-heart and black-heart malleable cast iron in transport, electrical, and agricultural and other branches of engineering are quoted, their properties are described and numerous examples are discussed illustrating the rules which lead to satisfactory design.—J. G. W.

Present State of Annealing of Malleable Iron in Gas Atmospheres. P. F. Hancock. (British Cast Iron Research Association: Giesserei, 1951, vol. 38, May 31, pp. 245–255). A review of practice in Great Britain is given and data are quoted on the requirements of the protective gas atmosphere. Annealing curves, and the applications of different types of furnace are discussed.—J. G. W.

On the Metallurgy of Annealing White Malleable Iron with Special Reference to Gas Malleablizing. F. Schulte. (Giesserei, 1951, vol. 38, May 3, pp. 197–205). Thick-walled castings may be decarburized just as effectively in a gas atmosphere as by annealing with ore. The method of matching annealing temperature and gas atmosphere so as to avoid scaling is explained with the aid of graphs and the connection between temperature, gas composition, and equilibrium carbon content is pointed out, as well as the great influence of annealing temperature on the rate of decarburization. The decarburization is independent of the composition of the casting. Graphitization proceeds faster at high temperatures, is slowed down by the presence of hydrogen, though only slightly at 1050° C.; it is greatly influenced by the composition of the casting. Attention is drawn to the suppressing tendency of silicon and free sulphur. It is also pointed out that machinability and toughness of thick-rolled castings may be improved by re-annealing which leads to the formation of globular pearlite.—J. G. W.

Problems and Developments Concerning Malleable Cast Iron. B. Tyberg. (Gjuteriet, 1950, vol. 40, Nov., pp. 181–188). [In Swedish]. The author deals briefly with melting methods, the use of tellurium as a carbide stabilizer and of boron for balancing the influence of chromium. Methods of malleablizing cast iron are outlined.—B. S. E.

The Relative Effects of Chromium and Silicon Contents on Rate of Anneal of Black-Heart Malleable Iron. Part I—First Stage Annealing. J. E. Rehder. (American Foundrymen's Society, 1951, Preprint No. 51). Determination of the quantitative effects of chromium contents on the annealing rate of black-heart malleable iron in the first or primary carbide decomposition stage shows that chromium neutralizes the graphitizing effect of from four to five times its weight of silicon. The retarding effect of chromium on annealing rate can be compensated by increased annealing time, increased annealing temperature, increased silicon content, or a combination of all three since the effects are additive. Charts are presented from which the necessary changes in annealing practice can be determined.—P. C. P.

High Quality Cast Steel. A. Heuvers. (Giesserei, 1951, Special Issue 'Konstrukteur und Giesser,' pp. 20–23). The quality of steel castings depends primarily on the raw materials, foundry technique, heat-treatment, and alloy additions. The author lays particular stress on correct heat-treatment and demonstrates that, with suitable choice of raw materials and appropriate treatment, properties may be obtained equal to those of high-quality forgings. He also points out the scope for cast alloy steel in turbine, hydraulic, and high-pressure plant engineering.—J. G. W.

Review of Present-Day Steelfoundry Radiographic Practice: Application of Radioactive Isotopes in Industry. G. M. Michie. (Institute of British Foundrymen: Iron and Coal Trades Review, 1951, vol. 162, June 29, pp. 1493–1498; vol. 163, July 6, pp. 23–26, 28). The author reviews present-day practice in the examination of steel components of all sizes by radiographic techniques. Development since the war has included the preparation of a whole series of radioactive isotopes. Some of the available radiation sources, including artificially prepared radioactive isotopes, are referred to, and the safety precautions which must be taken when working with them are discussed. Finally, the field of application of radiography in the steel foundry is reviewed, reference being made to the interpretation of radiographs and the use of acceptance standards.—G. F.

The Use of Radioactive Isotopes in Materials Testing, Trials with Iridium 92. O. Vaupel and N. v. Wetterneck. (Metall, 1951, vol. 5, July, pp. 293–294). The authors conclude from preliminary tests of an Iridium 92 source of soft gamma rays that, compared with an X-ray installation, its use is limited to the examination of small steel and light alloy castings, and of weld seams. In order to attain reasonably good definition of photographs they recommend the use of lead foils instead of calcium tungstate screens, Ilford 'C' film, Ilford I.D. 42 high-contrast developer, and fairly long exposures. To halve the exposure they recommend the simultaneous exposure of two films placed between three lead foils. After development the two films are superimposed, so that the densities add up. Film blackening of doubtful origin can incidentally be diagnosed in this manner, for both films should, of course, present the same appearance.—J. G. W.

Cast Machine Elements. W. Trommer. (Giesserei, 1951, Special Issue 'Konstrukteur und Giesser,' pp. 24–40). The author discusses cast steel fluidity with reference to density variations as between different castings and their dependence on the design. He considers the properties of cast iron and steel, making reference to the diffusion treatment of unalloyed cast steel for improved resistance to corrosion, and concludes by discussing tests for porosity (the oil boiling test), and magnetic powder and X-ray methods.—J. G. W.

Production, Heat-Treatment, Welding, and Testing of High-Duty Steel Castings. F. Harms. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1951, vol. 6, Jan. 31, pp. 6–13). Present foundry practice for the production of high-duty steel castings, the choice of moulding sand and moulding practice, and the use of different melting furnaces are reviewed. In the heat-treatment section, general annealing practices for grain refinement, stress relief, and homogenizing, and special heat-treatments required by particular types of alloy steel casting are described briefly. A short section on welding mentions its use for repair of defects and joining of castings, with special reference to atomic arc welding and the welding of rust-, acid-, and heat-resisting steel castings. The section on testing deals briefly with mechanical, weldability, metallographic, and chemical tests and more fully with various methods of non-destructive testing: Mechanical, acoustic, magnetic, and X-ray. The final section is concerned with the advantages and methods of centrifugal casting.—H. R. M.

The Making of Steel Castings for Tank Track Links by the Continuous Process. C. J. Dadswell. (Journal of the West of Scotland Iron and Steel Institute, 1945–46, vol. 53, pp. 38–48). The development of track-link production from 1939 onwards is described. The materials first used were steel drop forgings, 14% manganese steel castings, white-heart malleable iron castings, and Ford 7A Iron castings. An output of nearly 6000 tons/month of castings was required, and it was decided to concentrate on the Ford 7A material. Accordingly several iron foundries were equipped with melting, moulding, heat-treatment, and other plant based on the information provided by the Ford Motor Co. Each melting unit consisted of two electric furnaces, one for melting and the other for holding liquid metal. Before these foundries were completed it was decided to use 14% manganese steel instead of malleable iron or Ford 7A Iron. The modifications necessary for this conversion are described, and the manufacturing processes are detailed. It is was found that manganese steel can be 'held' for at least 6 hr. without detriment. A description of the furnace and pouring practices is given. The methods of holding two manganese steels (C 0·4–0·5%, Mn 1·2–1·6%, and C 0·4–0·7%, Mn 0·85–1·05%) in an acid furnace are described.—P. C. P.

An Investigation of the Penetration of Steel into Moulding Sand. H. Petterson. (Jernkontorets Annaler, 1951, vol. 135, No. 1, pp. 1–43: American Foundrymen's Society, 1951, Preprint No. 61). The main investigation is based on immersion experiments with cylindrical sand 'cores' in molten carbon steel in a high-frequency furnace. It is shown how the rate of penetration varies with time of immersion, metal pressure, temperature and analysis, grain size of the sand, various additions to sand, etc. Standard castings have been employed for comparison. The two methods have given contradictory results as regards the effect of certain additions to the sand upon steel penetration. A study of slag formation shows that very little slag is formed at the sand/metal interface before the surface of a casting has solidified definitely. The metal pressure, the capillary forces, the original size of the pores in the sand, the resistance of the sand to enlargement of the pores, and the sand temperature are believed to be factors which determine the rate of penetration.—P. C. P.

Sand and Its Origin. S. Müller. (Giesserei, 1951, vol. 38, May 17, pp. 227–232). Sand is intermediate between stones and soils; it is the attrition product of eroded rocks. Recent investigations have shown that the laws according to which sand is sifted by running water lead to the predominance of grains ranging in size from 0·3 to 0·6 mm., which are also the principal constituents of moulding sands. For this reason suitable moulding sands are most readily found in the lower courses and tidal basins of rivers. Reference is also made to the connection between sifting process and grain shape, and to the impurities in quartz sand.—J. G. W.

Investigations of Moulding Sand Pits—Significance for Foundry Practice. H. Reininger. (Giesserei, 1951, vol. 38, Mar. 22, pp. 125–128). The author pleads that the foundry industry should take greater note of investigations of sand pits in order to exercise greater control over the material supplied. He suggests that where sands from different strata differ in their properties, blending should be carried out at the pit.—J. G. W.

Natural and Synthetic Foundry Sands. B. Agotai and J. Szekeres. (Öntöde, 1951, vol. 2, Feb., pp. 31–43: Kohászati Lapok, 1951, vol. 6, Feb.). [In Hungarian]. The Hungarian Iron and Steel Research Institute is now carrying out a systematic investigation of the Hungarian deposits of natural sands and materials suitable for making synthetic sands and is drawing up specifications for sand preparation. An indication is given on the scope of the research work carried out by this institute. A sand-preparation plant is being built which will supply to the foundries the basic types of synthetic sand. The methods of testing sands are described.—E. G.

Preparation and Recovery of Moulding Sand, Particularly for Steel Casting. K. Roesch. (Giesserei, 1951, vol. 38, Apr. 5, pp. 145–149). The sand is greatly affected by the high temperature and chemical reaction with steel near the mould surface. Iron silicates are formed, the clay is burnt and quartz grains are broken up. Recovery is, however, possible by air sifting and wet or hot dressing. The degree of recovery is dictated by economic considerations.—J. G. W.

The Significance of 'Loosening' Curves of Rammed Sands in the Testing of Moulding Sands. W. Reitmeister. (Giesserei, 1951, vol. 38, Feb. 8, pp. 54–57). The nature of swelling and contracting of sands with varying amounts of moisture is explained and the connection with gas permeability and strength demonstrated. Curves of specific volume against moisture content of typical German moulding sands are shown and their interpretation in terms of sand properties given.—J. G. W.

Compaction Studies of Molding Sands. R. E. Grim and W. D. Johns, jun. (American Foundrymen's Society, 1951, Preprint No. 19). The compression characteristics of Illinois fireclay, Illinois illite, Wyoming bentonite, and Mississippi bentonite bonded sands were studied by means of an apparatus especially designed for the purpose, using varying amounts of sand–clay–water components. Illite and fireclay exhibited properties distinctly different from those of the bentonite bonded sands. Under like conditions, compression decreased in the order fireclay, illite, Wyoming bentonite, and Mississippi bentonite. Compression characteristics were correlated with differences in gross bulk densities. The relationships between compressibility, gross bulk density, maximum green strength, and dry strength were brought out.—P. C. P.

Foundry Innovations Produce Big Savings. A. S. Hall. (Iron Age, 1951, vol. 167, Mar. 1, pp. 110–113). Changes in the methods and equipment at the Buick grey-iron foundry have yielded economies quite out of proportion to the cost of the alterations. The handling of sand and moulds has been simplified, castings are automatically sorted, and certain cleaning operations have been mechanized.—A. M. F.

Urea-Formaldehyde As a Core Binder. C. Nilsson. (Gjuteriet, 1950, vol. 40, Feb., pp. 17–21). [In Swedish]. Foundry sand of 0·27 mm. mean dia. with additions of 1·25% of 50% aqueous solution of urea-formaldehyde, 1·75% dextrine, and 0·25% kerosene, is recommended as a core mix. A small addition of a few per cent of water gives higher baked strength at the expense of the green strength.—B. S. E.

Core Production Problems. S. Toresson. (Gjuteriet, 1950, vol. 40, June, pp. 81–88). [In Swedish]. Of numerous binders investigated preference has been given to melamine-formaldehyde resin mixed with dextrine.—B. S. E.

Self-Setting Mould and Core Sands for Foundry Purposes. E. Westerling. (Gjuteriet, 1950, vol. 40, Dec., pp. 203–207). [In Swedish]. The merits of different types of air-hardening cement sand and binder oil are briefly reviewed.—B. S. E.

Pouring Time and Its Relation to the Solution of Gating Systems. J. Kieswetter. (Hutnické Listy, 1951, vol. 6, Jan., pp. 14–22). [In Czech]. The general conditions which arise during pouring of the liquid metal into the mould are reviewed. The factors affecting the pouring time are then mathematically analysed and formulæ are derived for calculation of the pouring time and the dimensions of gating systems for grey-iron castings. Examples of the application of these formulæ are given. The author presents a table of pouring times for castings weighing 10 kg. to 40 tons, with

wall thicknesses of 3 to 55 mm. The author's formula for pouring times differs from that of H. W. Dietert.—E. G.

Gate Design and Its Significance in the Production of Sound Castings. H. U. Doliwa. (Giesserei, 1951, vol. 38, Feb. 8, pp. 49–51). The author believes that gate design should be placed in the hands of the pattern designer or maker. He demonstrates how the correct form of gate to give the desired pouring time may be calculated. The permissible pouring velocity is a function of the abrasive resistance and shear strength of the moulding material and should be determined experimentally for each material.—J. G. W.

The Plus and Minus of Steel Precision Investment Castings. A. C. Williams. (Materials and Methods, 1951, vol. 33, May, pp. 88–91). Investment casting of steel and high-temperature alloys should only be used where its inherent advantages can be exploited. The lost-wax method of precision casting should not be specified for a part without studying the problem from the following angles: Size, dimensions and tolerances, metallurgical quality, and cost.—P. M. C.

Precoat Materials for Investment Casting. W. F. Davenport and A. Strott. (American Foundrymen's Society, 1951, Preprint No. 27). Various ceramic oxides, alumina, silica, zirconium silicate, and magnesia were investigated as possible precoating materials. These materials were evaluated by casting a heat-resistant alloy, a stainless steel, and an alloy steel into the precoated mould. The castings were examined to determine the best precoating material for each alloy cast. The precoats were evaluated on the basis of precoat adherence, surface smoothness, and degree of oxidation. The most satisfactory materials were found to be the alumina–silica composition.—P. C. P.

Frozen Mercury Patterns Add Flexibility to Precision Casting. A. H. Allen. (Steel, 1951, vol. 128, Mar. 19, pp. 66–69). Precision casting a variety of ferrous and non-ferrous metals and alloys in ceramic moulds to tolerances of $\pm$ 0·002 in. and in a size range from about 90 lb. down to a few ounces is being carried out successfully with the novel use of frozen mercury as a pattern material instead of the conventional wax. The special silica-base ceramic shell mould has inherent high gas permeability and good thermal conductivity.—A. M. F.

New Combined Casting Process for Aluminium and Iron. G. Gürtler. (Metall, 1951, vol. 5, June, p. 250). This is a brief note on the 'Al-Fin' process developed by the Fairchild Engine and Airplane Corporation, Farmingdale, L.I., New York. The process is suitable for the manufacture of castings which combine the strength of steel with the lightness and high thermal conductivity of aluminium, *e.g.*, for cylinder liners and heads, brake drums, and all kinds of heat exchangers. The process consists of dipping iron or steel parts into molten aluminium or certain aluminium alloys. An intermediate $FeAl_3$ layer is formed and ensures perfect bonding between the two metals.—J. G. W.

The 'C' Process. (Foundry Trade Journal, 1951, vol. 90, Mar. 15, pp. 281–284). This process (the Croning process) has been described by B. N. Ames, S. B. Donner, and N. A. Kahn (*see* Journ. I. and S.I., 1951, vol. 168, May, p. 97).

Plant Construction—Completion of New Works for Gibbons Bros. (Iron and Steel, 1951, vol. 24, July, pp. 337–338). **New Works of Gibbons Bros. Ltd. at Lenches Bridge, Pensnett, Worcs.** (Iron and Coal Trades Review, 1951, vol. 162, June 22, pp. 1439–1440). A brief description is given of the new Lenches Bridge works of Gibbons Brothers Ltd., which has recently come into full production. The works is a self-contained unit, consisting of constructional shops, foundry, machine shops, and fitting and erection shops.—G. F.

A Modern Foundry. I. Hurtig. (Gjuteriet, 1950, vol. 40, Apr., pp. 51–56). [In Swedish]. Data and photographs from the Ljungmans Verkstäder foundry are presented. High melting capacity is facilitated by high-frequency furnaces with thin crucibles.—B. S. E.

The Husqvarna Concern's Foundries at Husqvarna and Norrahammar. (Gjuteriet, 1950, vol. 40, Aug., pp. 139–144). [In Swedish]. The Husqvarna works have a melting capacity of 150 tons of iron per day and a yearly production of 11,800 tons of small castings. A single shift of 305 workmen is employed. The Norrahammar high-frequency furnaces have a capacity of 5·5 tons each. Both works are highly mechanized. Photographs illustrate some of the equipments and operations.—B. S. E.

Mechanical Aids for the Foundry—New Devices for Speeding Output in Mass-Production and Jobbing Plants. (British Engineering, 1951, vol. 33, June, pp. 1122–1128). The layout of a very large British Railways foundry for the manufacture of railway chairs is described. Five pairs of machines are installed to feed the brake-block production side of the plant. Thirty tons of molten metal are required for the production of 14 railway chairs per minute and seven brake blocks per minute. Eight cupolas are installed, four of which are rated to give up to 20 tons/hr. of molten metal from each cupola, and the other four to give up to 8 tons. The entire operations are completely mechanized. Numerous foundry machines are illustrated. One of the best recent improvements is a multiple-belt storage hopper. Stationary knocking-out grid, sand crusher, and sand rammer are explained.—E. T. T.

Solidification of Cast Iron. M. Guédras. (Métallurgie, 1951, vol. 83, Apr., pp. 243–247). The mechanism of solidification in a straight casting is examined. The formation of combined carbon and graphite is studied and the phenomenon of foam graphite is described. The following hypothesis on the formation of graphite is formulated: The liquid iron constitutes a dispersed system which is subject to the influence of the Browning movement attributed to the incessant agitations of the molecules of the liquid which shake the minute grains, causing them to agglomerate and form separate lamellæ of graphite.—R. S.

Some Wet-Cleaning Plants of the Hydroblast Type. J. Sissener. (Gjuteriet, 1950, vol. 40, Aug., pp. 134–138). [In Swedish]. The hygienic advantages of wet-cleaning methods for castings are stressed, and some British examples of cleaning-shop layout as well as one Norwegian arrangement are sketched.—B. S. E.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

What's New in Heat Treating. H. E. Boyer. (Steel Processing, 1951, vol. 37, Jan., pp. 33–37, 42; Feb., pp. 83–86). The principle of the carbonitriding process is outlined, and the latest type of mechanized batch furnace for atmosphere heating operations is described and illustrated. This equipment is manufactured by the Dow Furnace Co., U.S.A. Carbon control during heat-treatment is also dealt with, and the latest type of carbon-control furnace (by Leeds and Northrup) is described and illustrated. Two portable gas generators are described and the use of lithium vapour for removing oxygen and water vapour from furnace atmospheres is outlined. The relatively new submerged-electrode salt bath is discussed, and the application of salt-bath heating to forging is mentioned.—P. M. C.

Gas Plays Important Part at Columbia's Sheet and Tin Mill. (Western Metals, 1950, vol. 8, Oct., pp. 37–39). The importance of natural gas in western U.S.A. is exemplified by modern installations at Columbia Steel Co's new sheet and tin mill at Pittsburg, California. Ten rectangular bell-type annealing furnaces, a 250-ft. continuous electrolytic tinning line, 14 hot-dip tinning pots, and a galvanizing line, all use natural gas for heating purposes. Brief descriptions of the processes and equipment are given.—P. M. C.

A Mechanized Laminated Spring Manufacturing Plant. (Engineer, 1951, vol. 191, Feb. 2, pp. 167–168). **Mechanised Production of Railway Laminated Springs.** (Engineering, 1951, vol. 171, Feb. 9, pp. 149–152). A description is given of the plant constructed by the English Steel Corporation at Grimesthorpe works for the production of railway laminated springs in quantity, with special reference to the heat-treatment. The quality of steel used and the methods of oil-quenching are described and details of the various mechanized operations are given. A layout drawing and photographs of the plant in production are also given.—M. D. J. B.

A New Mechanised Spring Plant. R. Fielding. (E.S.C. News, 1951, vol. 4, Spring Issue, pp. 2–7). A description is given of a new plant designed for the manufacture of heavy types of laminated spring at the works of the English Steel Corporation.—D. H.

Armour Plate: Continuous Treatment of Lighter Grades. H. Drever. (Iron and Steel, 1951, vol. 24, May, pp. 189–192). *See* "Heat-Treatment of Armour Plate," Journ. I. and S.I., 1951, vol. 169, Oct., p. 192.

Progress Review No. 16: Electric Furnaces. D. M. Dorey and I. Jenkins. (Journal of the Institute of Fuel, 1951, vol.

24, May, pp. 129–133). The furnaces dealt with are induction and dielectric heating furnaces; arc furnaces; resistor furnaces; and batch and continuous furnaces. Controlled-atmosphere furnaces and the treatment of charges in a controlled atmosphere are discussed. Radiant heating, as used for paint stoving, fabric-proofing, preheating plastics, setting synthetic-resin adhesives and for the drying of latex, gum and printing ink, is reviewed. The paper ends with a section on salt baths.—J. P. S.

Electric Furnaces for the Bolt and Nut Industry. (Machinery, 1951, vol. 78, Apr. 5, pp. 560–563). The operation of two continuous mesh-belt conveyor furnaces supplied by G.W.B. Electric Furnaces Ltd., Dudley, to Charles Richards and Sons, Ltd., Darlaston, is described. Each is rated at 105 kW. and designed for an output of 5 cwt./hr. Either furnace is used for hardening at 830–870° C. while the other is used for tempering the hardened parts at 500–700° C.—E. C. S.

Conveyor Furnaces: New G.W.B. and G.E.C. Mesh Belt Installations. (Iron and Steel, 1951, vol. 24, Feb., pp. 69–70). This article describes a new type of mesh-belt conveyor furnace, which is designed to operate at temperatures up to 1000° C.; it is used for a variety of purposes, including annealing, brazing, and sintering of metal powders. The heating chamber is divided into two or three independently controlled zones, and the exit end of the furnace is provided with a water-jacketed cooling chamber. A protective atmosphere may be used.—G. F.

The Heat-Treatment of Narrow Steel Strip by the Electric Direct Resistance Method. O. C. Trautman. (Wire and Wire Products, 1951, vol. 26, Mar., pp. 219–221). Details are given of the plant designed and manufactured by the Tranwood Engineering Co., Cleveland, Ohio, with the capacity to heat-treat 6000 lb. of strip per hour. Heating rate may be varied between 125° F. and 600° F./sec. It is claimed that strip heat-treated by this process has better physical and fatigue properties.—J. G. W.

Rectification of Neutral Salt Baths Operating at High Temperatures. S. M. De Poy. (Metal Treating, 1950, vol. 1, Nov., pp. 12–16). Three test runs were made on a neutral salt (95% $BaCl_2$, 5% NaCl), at 2225° F. to determine a process for eliminating oxides from the bath. One bath was rectified with silica, one with a graphite rod inserted wholly below the surface of the bath, and one bath was operated without the use of a rectifier. The results are shown in tabular form, the change in carbon content of the outside layers of specimens of high-speed steel being used as a criterion of the oxide content of the baths. It is shown that the graphite rod practically eliminates decarburization from the work passing through the bath. Elimination of the oxides also prolongs the electrode life of the furnace.—P. M. C.

Mass Marquenching Speeds Gear Output. W. B. Cheney and W. C. Hiatt. (Steel, 1951, vol. 128, Feb. 12, pp. 73–74). A type of interrupted quench is used for heat-treating gears and other transmission parts at the works of the International Harvester Co. In this process oil at 400° F. is used as the quenching medium and governing factors are furnace temperature, carbon concentration, agitation of quenching medium, time cycle in quenching medium, and transformation period. The use of quenching presses and special fixtures is eliminated and parts have a better service life and load-carrying capacity.—A. M. F.

The Skills Born of Specialization Solve Another Problem. A. E. Fulton. (Metal Treating, 1950, vol. 1, Nov., pp. 4–5). The author describes a heat-treating procedure evolved for C1118 steel shafts, $6\frac{1}{8}$ in. long and $\frac{3}{4}$ in. in dia. To obtain a case depth of 0·025–0·035 in. with a hardness of 66–72 on the Rockwell 45 N scale, and also to limit the eccentricity due to distortion to less than 0·005 in., the following procedure was evolved: (1) Carburize for 4 hr. in dry carburizing compound at 1700° F., (2) after unpacking, immerse in a weak (5%) sodium cyanide bath at 1500° F. until soaked through, (3) quench into nitrate salt bath at 425–450° F. for 4 to 5 min. and then air cool, (4) remove salt by immersion in boiling water for 10 min., and (5) temper at 400° F. in a gas-fired furnace for 1 hr.—P. M. C.

Diagrammatic Representation of Transformation Processes in the Heat-Treatment of Steel. A. Leon and F. Vitovec. (Betrieb und Fertigung, 1950, vol. 4, Oct., pp. 165–175). Four different diagrams have been used in Germany for studying and demonstrating various heat-treatment processes: The temperature-concentration diagram (the normal constitution diagram replotted for various cooling rates); the time/temperature diagram (**S**-curves); the temperature/transformation-rate diagram; and the temperature/cooling-rate diagram. These are compared and the second is found the most generally useful. This diagram is then used as a basis for a brief discussion of quenching and tempering, interrupted quenching, isothermal hardening, martempering, austempering and patenting, deep-freezing, and surface hardening.—H. R. M.

The Accuracy of the Calculation of Carbon Penetration in Carburized Steels for Routine Use. A. Slattenschek. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 117–130). The part played by surface phenomena in the carburizing of steel is discussed theoretically and some observations are made on a paper on the calculation of carbon penetration by H. Schrader and R. Moufang (*see* Journ. I. and S.I., 1951, vol. 168, July, p. 315). The results of these two workers are employed to illustrate the validity of the newly derived 'general carburizing line' equation.—J. P.

Salt Quench of Steel Parts Gives Uniform Hardness at Utah Plant. J. Joseph. (Western Metals, 1950, vol. 8, Nov., pp. 30, 31). A brief description is given of a salt-quenching technique developed by the Eimco Corp. of Salt Lake City (U.S.A.). The 72-in., 888-lb. blade, and the 2684-lb. backplate of a heavy mining scraper are successfully through-hardened without cracking by quenching into salt at 400–600° F. These parts are of Cr–Mo alloy steel, and the electrically heated 'Ajax' salt tank contains 90,000 lb. of a potassium-nitrate/sodium-nitrite mixture.—P. M. C.

The Function of Energizers in Pack Carburizing. A. Hultgren. (Journal of The Iron and Steel Institute, 1951, vol. 168, July, pp. 245–259). A number of small-scale pack-carburizing tests on a low-carbon steel, mainly at a carburization temperature of 925° C., are described. Various ways in which the energizers K_2CO_3, Na_2CO_3, and $BaCO_3$ may be placed in the box with crushed charcoal and with the objects to be carburized are investigated, and also the effect on carburization of different methods of sealing the box. It is shown that K_2CO_3 or Na_2CO_3 may be effectively applied as a layer on top of the charcoal, whereas $BaCO_3$ may be applied as a thin coating on the surface of the objects to be carburized, preferably with a bonding agent such as lacquer. The effects of the different energizers are compared, and the conditions required for good carburization when a carburizer is used repeatedly are determined; it is found that a minimum amount of fresh charcoal, equal to about 10% of the charge, must be added to and mixed with the spent carburizer each time it is re-used, a small amount of energizer being added occasionally to compensate for the slight loss that may occur by evaporation and in handling. Experiments are described in which, to determine the reactions that take place in a carburizing box, a 1 : 1 N_2–CO_2 mixture is allowed to pass at a measured rate of flow through a layer of heated charcoal, with and without admixed substances, and the amount of CO_2 remaining in the outgoing gas is measured. The experiments indicate that a rapid reaction in which the energizer takes part, and which has a low CO_2 value at equilibrium, determines the composition of the gas in the box.

Austempering of Proving Rings with Minimum Distortion. F. Heinzelman, jun. (Metal Treating, 1951, vol. 2, Jan.–Feb., pp. 4–5). The heat-treatment of several proving rings, 5 in. in dia., 1 in. wide and 0·1 in. thick is described. The rings were made of SAE 52100 steel, and a minimum of distortion during heat-treatment was required. The following treatment was evolved, resulting in a Rockwell hardness of 45–49, and a maximum distortion of 0·002 in.: (1) Stress relieve at 1200° F., (2) preheat in neutral salt at 1200° F. for 10 min., (3) heat in neutral salt at 1500° F. for 10 min., (4) quench in salt at 600° F. for 20 min., and (5) air cool and temper at 750° F. for 1 hr.—P. M. C.

Induction Hardening and Brazing. R. J. Brown. (Metal Treatment and Drop Forging, 1951, vol. 18, May, pp. 214–221). The practical applications of the high-frequency method of heating are discussed with reference to actual production of components in the motor industry. The equipment and types of steel suitable for skin hardening and local hardening are described, and the design of transformers and inductors, power requirements, and the general economics of this method of heating are discussed.—P. M. C.

High Frequency Heating. (Australasian Engineer, 1951, Apr. 7, pp. 82–84). A brief general review is given of both eddy-current and dielectric high-frequency heating methods. The application of the former to the hardening of steel, and for melting, soldering, and brazing operations is described. The latter method is used in the woodworking, plastic, and other non-metallic industries for glue setting, laminating, welding, and drying operations.—P. M. C.

Transverse Flux Induction Heating. R. M. Baker. (Transactions of the American Institute of Electrical Engineers, 1950, vol. 69, pp. 711–719). The author describes transverse flux heating in which magnetic flux is directed perpendicular to the surface and through the strip instead of along its length. It is suitable for stainless steel and non-ferrous metal strip. Two 300-kW. pilot installations have been made. Formulæ are derived for the design of installations which also enable performance to be predicted. Frequencies will generally range from 60 to 10,000 cycles/sec. An efficiency of 80% or better can be expected in most applications. The method also has certain edge-heating applications.—R. A. R.

Carbo-Nitriding. (Iron and Steel, 1951, vol. 25, June, p. 232). This article is a brief discussion of the principles of the carbonitriding method of producing a hard case on steel. The advantages of carbonitriding over normal carburizing practice are given.—G. F.

Nitriding : Developments and Applications for Steel. R. W. Allott. (Iron and Steel, 1951, vol. 24, Apr., pp. 145–148). The author reviews some of the recent technical developments in the field of nitriding, and describes the theory of the process and the equipment used. The expansion of the range of alloy steels suitable for nitriding is considered, and special mention is made of the development of the graphitic Nitralloy steels and some of their possible applications.—G. F.

Carbonitriding Produces Hard Case at Lower Temperatures. S. Damon. (Materials and Methods, 1951, vol. 33, May, pp. 64, 65). Where large quantities of small parts can be treated simultaneously, ' dry cyaniding ' has the advantages of lower cost, less distortion, and cleaner, safer operation. The parts are heated in a metered atmosphere containing ammonia and a carburizing gas such as methane, followed by oil quenching or atmosphere cooling. The process is operated at temperatures in the 1110–1560° F. range. Examples of typical cases are shown by microphotographs.—P. M. C.

The Nitriding of High Speed Steel Tools in No. 90 Casing Salt. (Metal Treating, 1951, vol. 2, May–June, p. 13). The cutting ability and effective life of most high-speed steel tools are both claimed to be improved by treatment in a proprietary salt marketed by the Park Chemical Co., Detroit, U.S.A. The salt produces a glass hard case of iron nitride. Brief details of its use are given.—P. M. C.

Carbonitriding Gains Wider Acceptance. E. J. Pavesic and A. E. Uitti. (Iron Age, 1951, vol. 167, Mar. 1, pp. 101–104). A description is given of a high-production carbonitriding furnace built by the Lindberg Engineering Co. to replace existing liquid cyaniding plant. The atmosphere consists of an endothermic carrier gas, anhydrous ammonia and a mixture of natural and coke-oven gas. Advantages include automatic cycle of operation, a safer process than liquid cyanide, lower raw-material costs, and less distortion.—A. M. F.

Local Heat-Treatment for Stress Relief. R. Schnabbe, R. Mailänder, and H. J. Wiester. (Brennstoff, Wärme, Kraft, 1951, vol. 3, Mar., pp. 79–85). The effectiveness of local annealing of welded joints was examined by strain measurements on an experimental welded boiler drum. Industrial conditions were simulated by welding the boiler in working position. Comparative strain measurements were carried out after local annealing and after annealing of the whole drum. Data and details are quoted. Although local annealing did not achieve complete removal of strain, results were satisfactory, residual strains being small and nowhere more than 10 to 15 kg./sq. mm. Tensile strength, bending, and notch impact tests, as well as textural examination, also gave satisfactory results.—E. C.

A Method for Annealing Metal Powders without Sintering. F. W. von Batchelder and H. E. Stauss. (Review of Scientific Instruments, 1951, vol. 22, June, pp. 396–397). The metal powder to be annealed is mixed with a large quantity of a second powder that is chemically inert with respect to the metal, the mixed powders are annealed and are then separated by dissolving out the inert powder. In this way gold, silver, and iron powders have been annealed in sodium chloride without sintering.—T. E. D.

Some Aspects of Annealing Atmospheres for Tin Plate Strip. J. R. Trimble and J. E. Hill. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 70–83). The authors review progress in the past 20 years in the production of tinplate. Tonnages have increased from a few thousand to five million tons per annum. The importance of controlled atmospheres in annealing steel for tinplate is considered in detail. The merits of ' Deox ' gas, lean gas, and nitrogen–hydrogen gas as protective atmospheres when annealing tinplate are discussed. The effects of controlled atmospheres on the corrosion resistance of tinplate are explained and the results of full-scale tests carried out on large numbers of samples to determine corrosion resistance are described.—M. D. J. B.

A 1·5-MW. Annealing Furnace. A. Lazek. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1951, vol. 6, Mar. 1, pp. 69–71). An electric annealing furnace large enough to take such components as welded hydraulic pipes, boiler tubes, turbine housings or chemical vessels has been installed in Austria. The inside dimensions are $3{\cdot}1 \times 3{\cdot}1 \times 10{\cdot}65$ m. and the hearth, which is a self-propelled carriage with 16 roller-bearing wheels running on rails, will carry 60 tons. The eight heating zones are independently regulated and temperatures are measured by thermocouples. The furnace is designed for a maximum temperature of 1050° C., making it suitable for normalizing, case-hardening, or a quenching and tempering treatment in addition to stress-relief annealing. Current is supplied from 20-kV. mains through two transformers, one of 1000 kVA. and the other 640 kVA., which reduces it to the working voltage of 400/230 V.—H. R. M.

Determination of Residual Stresses in a Cylinder of Cementitic Steel. J. Pomey, L. Abel, and P. Yenin. (Comptes Rendus, 1951, vol. 232, Apr. 30, pp. 1641–1643). Quantitative analysis of the development of stresses during quenching shows that the cemented layer deforms during the isothermal bainite transformation in the core in such a way that the stresses due to the martensite transformation in this layer are predominant. The order of magnitude of the plane compressive stresses in the cemented layer conforms to previous measurements of Hertzian hardness.—A. G.

Small Parts Bore Hardened on Screw Machines. A. H. Allen. (Steel, 1951, vol. 128, Mar. 26, pp. 74–77). The Ford Motor Co, Detroit, has set up induction-hardening equipment on automatic screw machines for hardening the inner surfaces of small bushings and bearing races. Speed, cleanliness, and precision of hardening are the advantages gained.—A. M. F.

New Quenching Methods Avoid Cracking—Improve Performance. J. H. Chapman. (Western Metals, 1950, vol. 8, July, pp. 22, 23 : Metal Treating, 1951, vol. 2, May–June, pp. 4–5). The following processes, both of which eliminate the hazards of cracking and distortion are briefly outlined : Austempering—whereby steels of suitable composition are quenched in a bath at constant temperature and held for a sufficient time to transform the austenite isothermally to bainite ; and martempering—whereby the steel is quenched rapidly into a bath held just above the martensite change point, and then cooled in air, with consequent transformation of the austenite to martensite. Both methods minimize the high stresses usually induced in drastically quenched high-carbon or alloy steels.—P. M. C.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Methods. J. C. Stevens. (North East Coast Institution of Engineers and Shipbuilders, Mar. 30, 1951, Preprint : Iron and Coal Trades Review, 1951, vol. 192, Apr. 6, pp. 793–797 : Engineering, 1951, vol. 171, May 4, pp. 541–543). This paper deals with the manufacture of heavy forgings up to about 60 tons in weight. The precautions necessary in heating are stressed, and the handling equipment is briefly described. The forging of rotors and rudderstocks is used as an illustration of various forging methods. The twisting of crankshafts including two, four, five, seven and eight throw types is considered in detail, and reference is made to the necessity of ensuring that grain flow is in the correct direction. Three methods of making hollow forgings are described, namely becking, becking and drawing, and drawing. Machining allowances and forging defects are considered.—P. C. P.

Roll Forging Steel Rings. W. H. Newsome. (Steel Processing, 1951, vol. 37, Mar., pp. 126, 127, 141). The article

describes a roll-forging process developed by C.B.S. Steel and Forge, Inc., Los Angeles. The process is used to fabricate weldless steel rings, and consists briefly of using steel rolls and hydraulic pressure to convert prefabricated 'doughnuts' into rings with outside diameters of 8 to 76 in., lengths up to 20 in., and weights of 50 to 2500 lb. A round mandrel is passed through the centre hole of the blank, and the outer surface rides on three rolls arranged in an arc. The stock is then compressed between the centre mandrel and the outer rolls and is rotated at the same time. Rings produced in this way are claimed to have excellent mechanical properties and the cost is very low.—P. M. C.

The Counter-Blow Forging Hammer—Its Design and Applications. B. Anscher. (Steel Processing, 1951, vol. 37, May, pp. 226–230, 257). This type of hammer, which was developed in Germany in the early 1930's, has an air or steam driven upper ram which is mechanically or hydraulically coupled with a lower ram, so that the two rams move in a counter direction to each other at the same speed. Advantages claimed for such hammers are higher efficiency (due to elimination of anvil losses), lower overall weight, less wear and breakage, and more uniform metal flow. Models of such hammers being made by Hydropress Inc., New York, are described, and the application to heavy closed-impression die forging is discussed.—P. M. C.

Mechanical Forging Presses. (Engineer, 1951, vol. 191, June 22, pp. 839–840). This article describes a new range of mechanical forging presses developed by B. and S. Massey, Ltd., of Openshaw, Manchester, for certain classes of die forging and extrusion work where the high production speeds of these machines can be used to full advantage. Their design features and operating capabilities are given. The high-speed presses are made in sizes from 250 to 3000 tons, and the low-speed presses from 250 to 1000 tons.—M. D. J. B.

Forging Operations in Steam and Diesel Locomotive Practice. R. E. W. Harrison. (Steel Processing, 1951, vol. 37, Apr. pp. 169–171; May, pp. 239–244). The diesel engine is gradually replacing steam in the U.S.A., and it is noteworthy that the more exacting demands of the diesel engine have so far been met by the jobbing forge shop. Several typical diesel engine parts are described and illustrated, and current practice for several steam locomotive forgings is described. Appended is a list of 25 publications, with short abstracts giving details of U.S. forging practices as applied to building and maintenance of steam and diesel locomotives.—P. M. C.

Automatic Hot Pressing of Nuts. F. B. Hatebur. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1951, vol. 6, Jan. 31, pp. 4–5). A fully automatic hot pressing machine, made by the Swiss firm of Hatebur, is described. The nuts are made from round bar stock which is fed through a furnace to heat it to the forging temperature. Slugs of the required length are automatically cut off the end of the bar and passed in turn to three pressing stations at which the following operations are carried out: Rough pressing to solid hexagonal blank; finish pressing of hexagon, forming chamfers, and recessing hole from both sides; and punching out remaining metal from hole. Up to 35,000 nut blanks per 8-hr. shift can be produced. One setting of the tools makes 100,000 nuts and the waste material is only 6–8%.—H. R. M.

The Inspection of Drop Forgings. F. E. Stokeld. (Engineering Inspection, 1951, vol. 15, Spring Issue, pp. 8–23). After a brief review of the methods, tools, and equipment used in drop forging, the author discusses the complete inspection of the product. This work involves both metrology and metallurgy, and after referring to the standard tolerances recently formulated by the National Association of Drop Forgers and Stampers, the inspection procedure is further described with particular reference to forging stock, heating of stock, shape and dimensions of the product, flow lines, heat-treatment, mechanical tests, descaling, surface soundness, interior soundness, and finally full identification and records of complete history.—P. M. C.

Progressive Maintenance Saves Western Forge Shop Many Costly Repairs and Equipment Failures. (Western Metals, 1950, vol. 8, July, pp. 29, 30). The importance of cleanliness and regular preventive maintenance in the Forge Division of the Erle M. Jorgensen Co., Los Angeles, is stressed.—P. M. C.

Automatic Spinning of Stainless Steel in Production. L. W. Court. (Materials and Methods, 1951, vol. 33, May, pp. 86, 87). A machine for spinning type 302 stainless steel has been developed by the International Harvester Co. (U.S.A.). The parts produced are variations on the shape of a truncated cone, and are spun from discs up to $10\frac{7}{8}$ in. in dia. and $\frac{3}{16}$ in. thick. The machine consists of a revolving face plate on which the conical spinning mandrel or die is located. A square driving pin projects a short distance above the centre of the mandrel and fits into a similarly shaped hole in the centre of the blank. A carbide-faced spinning roll is brought against the work near the centre of the blank, and feeds downwards and outwards to form the cone. This procedure has eliminated the intermediate anneals and cleaning operations which were necessary when the same parts were produced by pressing.—P. M. C.

Empirical Time Standards For Punch Press Operation. C. N. Harwood. (Steel Processing, 1951, vol. 37, Mar., pp. 117–121). The use of empirical time standards in short-run punch press stamping is described. The method offers advantages over conventional time-study methods in this type of operation, and serves as a valuable estimating tool for the stamping shop. The author describes how each element of the pressing operation (*e.g.*, type of press, method of location of piece, type of hand operations) is allocated a 'factor value,' and how the sum total of the factors for a particular operation enables the pieces produced per hour to be estimated.—P. M. C.

Universal Stamping Dies. F. Strasser. (Steel Processing, 1951, vol. 37, Apr., pp. 182, 183, 205). The author describes how certain simple types of die, *e.g.*, for cutting-off, blanking, bending, washer forming, etc., may be used to produce differently shaped and sized articles. This is accomplished by such simple acts as changing feed direction, limiting the press stroke, or using only a part of the die.—P. M. C.

The Use of Sintered Carbides for Stamping Tools. R. Champeval. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1951, vol. 6, Mar. 1, pp. 61–62). Sintered carbide tools are now used extensively for light electrical stampings. When carbide dies are used with a steel punch, this must be correctly hardened and accurately made, and the whole press must be accurate in its action to avoid die breakage. Overloads must be prevented. The advantage of carbide tools is their very low wear (20 to 100 times less than steel) with consequent greater accuracy of product over a long period. Their greater initial cost makes them most suitable for producing large numbers of stampings.—H. R. M.

Alloy Steel Prop Blades Made by Hot Extruding. (Materials and Methods, 1951, vol. 33, May, pp. 66–68). This is a pictorial story in which seven photographs show stages in the production of aeroplane propeller blades from 400-lb. billets of Cr–Ni–Mo steel. Three extrusion operations in a 5500-ton press produce a hollow tube, which, after flattening and twisting, becomes a propeller blade 10 ft. long and 200 lb. in weight.—P. M. C.

Extrusion. H. D. Feldmann. (Zeitschrift des Vereines Deutscher Ingenieure, 1951, vol. 93, June 1, pp. 434–443). The development and applications of extrusion are described, as well as materials suitable for the process and conditions for commercial production. Examples are given of calculations of force and power requirements, and guidance on the choice of suitable presses and tools is given according to modern practice.—J. G. W.

Deep Drawing of Hollow Bodies from Thick Steel Sheets. U. Bauder. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 500–512). The formation of closed-end, hollow cylindrical bodies by deep drawing of thick steel sheets, in such a way that the base remains essentially unchanged and the walls are progressively thinned, is described. The formation of the initial cup, the drawing of the wall and the influence of tools, type of press, and friction, are discussed at length. [A French version of this paper appeared in Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 299–302].—J. P.

Production of Drawing Dies for Steel Sections from Tool Steel. F. Boehm. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 522–523). The methods of making such dies and the most suitable dimensions for drawing round, square, and hexagonal sections are described.—J. P.

The Reduction of Internal Stress in Cold-Drawn Rods by Polishing in the Coining Press. H. Bühler. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 521–522). Investigations have shown that polishing in the coining press, *i.e.*, giving very slight reductions, is a means whereby dangerous tensile stresses in the surface layers of cold-drawn rods can be eliminated and converted into compressive stresses. [A

French translation of this paper appeared in Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 299–302].—J. P.

A Review of Impact Extrusion and Some Related Processes. G. Sachs. (Sheet Metal Industries, 1951, vol. 28, June, pp. 533–538, 546). The author describes and classifies the various processes termed piercing, extrusion, impact extrusion, extrusion forging, coining, and sizing. Factors considered include force–stroke curves, relations between extrusion stress and reduction, effect of temperature and forming speed, and typical tool arrangements.—P. M. C.

Stress Analysis of Reverse Redrawing of Cylindrical Shells. S. Y. Chung. (Sheet Metal Industries, 1951, vol. 28, May, pp. 453–458). The author discusses the importance of reverse redrawing, and then formulates a theory for the stresses produced in a blank during drawing. From the theory, punch loads can be calculated, and experimental results are shown which agree fairly well with those theoretically predicted. It is concluded that the present analysis is quite satisfactory for ascertaining press capacities for reverse redrawing operations.—P. M. C.

Plant Difficulties in Seamless Tube Manufacture. F. M. Clark. (Australian Institute of Metals : Australasian Engineer, 1951, Mar. 7, pp. 54–60). Three problems, arising in the push-bench process of tube manufacture are discussed in general terms. The author first deals with the fracture of a drive shaft which normally transmits 600 h.p. at 80 r.p.m. and carries a peak load of 1500 h.p. The elimination of the trouble by new keyway design and stricter attention to the physical properties of the steel is described. The welding of the hot steel ' bottle ' to the mandrel during drawing is next discussed; this trouble was corrected by limiting the maximum operating temperature of the mandrels. Finally, fracture of the steel being processed is discussed, with particular reference to the forces involved along the die bed, the relative temperatures of ' bottle ' and mandrel, and to friction.—P. M. C.

Patenting and Drawing Tests on Austenitic Coarse- and Fine-Grained Steel Wires and the Influence of Small Contents of Carbide-Forming Elements. W. Papdorf. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 87–98 ; Iron and Steel Institute, 1951, Translation Series, No. 421). Coarse-grained steel should be used for producing high-quality steel wire. If only fine-grained material is available, patenting must be carried out at a very high temperature, for which furnaces are not suitable and which may lead to marked decarburizing and loss of lead ; there is even then no certainty that the patenting has been carried out properly. Carbide formers are undesirable in steel which is to be patented or subjected to other heat-treatments, *e.g.*, soldering. The investigations and results of work carried out in the last 20 years are reviewed. Though the tests carried out so far on transformation temperatures and diagrams give only general clues to the fundamentals of the processes, they serve as an indication for further work. Proposals for further investigations are made.—J. P.

Function of Patenting in Manufacture of High-Tensile Steel Wire : Influence of Austenitic Grain Size and of Traces of Carbide-Forming Elements. (Iron and Coal Trades Review, 1951, vol. 163, July 6, pp. 33–34). This article is a review of W. Papsdorf's paper in Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 87–98 (*see* preceding abstract).

Routine Measurement of the Bearing Length of Wire-Drawing Dies. W. Lueg. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 517–521). An apparatus is described, in which a drawing die, supported on a horizontal platform, is moved till it engages with one and then with a second tapered needle mounted vertically over the first. By adjusting a pointer to a value corresponding to the die diameter, the movement necessary to effect the engagement with the two needles is converted directly to read bearing length. A consideration of the effects of rounding of the ends and of slight conical shape of the bearing surface shows that, in general, the two effects cancel out and can be neglected.—J. P.

The Use of Tungsten Carbide Dies in Wire Drawing and Nail Making. E. C. Kinyon. (Wire and Wire Products, 1951, vol. 26, Mar., pp. 215–217, 260–262). The author traces the history of wire-drawing dies, the internal shape of tungsten carbide dies and its importance in the drawing process, and the performance of tungsten carbide dies. With regard to tungsten carbide nail-gripper dies, the author points out that they demand higher-quality wire and a higher standard of machine maintenance for satisfactory operation.—J. G. W.

Wire-Drawing Die Bores. R. M. J. Withers. (Metal Treatment and Drop Forging, 1951, vol. 18, May, pp. 191–194). The author surveys the various methods which have been used for examining and plotting the profiles of wire-drawing dies of small diameter. After describing several optical projection and lever feeler devices, he outlines the construction and method of operation of a bore profilometer developed by B.I.S.R.A., and now commercially available. This instrument, in which an autocollimator is used to indicate the position of a probe traversed through the die, will measure profiles and bore diameters in the 0·015–0·500-in. range within 0·0001 in.—P. M. C.

Prediction and Production of Springs by Statistical Quality Control. E. E. Schiesel. (Wire and Wire Products, 1951, vol. 26, May, pp. 385–388). Details are given of the use of statistical quality control in the production of a straight open compression spring and in altering the customer's specification so as to bring it in line with production facilities. Control charts were used on the coiling machine, after stress-relieving heat-treatment, and after plating. The controlled variable was load for a fixed height of the spring. A special load tester had to be devised for the purpose. The author stresses the need for adapting the statistical methods to the stages of manufacture.—J. G. W.

Wire for Fasteners. S. W. McDermott. (Wire and Wire Products, 1951, vol. 26, June, pp. 489–491, 509–510). The author describes the material used in the production of cold-headed hexagon steel nut blanks in sizes ranging from $\frac{1}{4}$ in. light to 1 in. heavy, and $1\frac{1}{8}$ in. light. Fully rimming steel, 0·08% max. C, 0·03% max. P, 0·075/0·10% S, and 0·50/0·60% Mn, is used. Full particulars are given of the hot-rolling, wire-drawing, and cold-heading operations.—J. G. W.

Operating Results with a Long-Distance Gas-Fired Wire-Patenting Furnace. F. Domes. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 512–516). The operational results obtained with a gas-fired furnace, constructed on modern thermal principles, are described. As compared with the original coal-fired furnace, heat requirements were reduced by about 78% and the hourly through-put raised by 45% with a lead consumption of 1·8–1·9 kg./ton. A comparison of figures in the literature indicates the progress thus made in the construction of wire-patenting furnaces.—J. P.

ROLLING-MILL PRACTICE

Solution to the Rolling Problem for a Strain-Hardening Material by the Method of Discontinuities. Alice Winzer. (Journal of Applied Mechanics, 1951, vol. 18, Mar., pp. 90–94). The problem of drawing and rolling of a thin plastic sheet between cylindrical guides was investigated by H. I. Ansoff. The same type of problem, but under the assumption that the material displays strain-hardening, is analysed in this paper by the method of discontinuities. It is expected that the results constitute a close approximation to results based upon a continuous solution.—J. P. S.

Power for Hot Strip Mills. A. F. Kenyon. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 80–88). The author considers in detail the three items peculiar to modern hot strip mills : (1) Mill arrangement to enable large coils to be rolled, and the resulting use of synchronous motors for roughing-stand drives. (2) Use of ignitron rectifiers for finishing-stand direct-current power supply. (3) Installation of reversing finishing mills for moderate tonnage production. Considerable technical and statistical information, numerous photographs, and layout drawings are given.—M. D. J. B.

The Use of Roller Bearings in the Stands of Mills for Hot-Rolling Thin Sheets. W. Krämer. (Iron and Steel Institute, 1951, Translation Series, No. 420). This is an English translation of a paper from Stahl und Eisen, 1950, vol. 70, Oct. 12, pp. 925–929 (*see* Journ. I. and S.I., 1951, vol. 168, June, p. 196).

Selecting Gears for Rolling Mill Equipment. E. C. Denne. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 62–68). This paper brings out the importance of factors influencing the selection of the type of gear set for each application. No single type of gear set, material specification, or hardness specification can have universal application and the proper gear set is one which economically satisfies the variable conditions under which it must operate. After examining considerations affecting the design and characteristics of gears the author considers drives for entry and delivery feed rollers for blooming and slabbing mills ; front and back table bevels for

blooming and slabbing mills; pinion stands; screwdown worm gear sets; ingot car gears; and timing gears.—M. D. J. B.

Details of the New 42-in. Slabbing Mill Installed at the Works of John Summers and Sons Ltd. at Shotton. (Sheet Metal Industries, 1951, vol. 28, Mar., pp. 219–222, 228). *See* Journ. I. and S.I., 1951, vol. 168, June, p. 194.

The Continuous Merchant Mill. L. C. Sowell. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 72–76). A description is given of the Aliquippa mill of the Jones and Laughlin Steel Corp. erected in 1924 and believed to be the first continuous mill to roll shapes. Layout drawings and technical and operating data are given. Whilst from a production standpoint, the semi-continuous cross-country mill appears to be preferable to the straight-away continuous mill, the author suggests that, if the difference in commodities and footweights and the lack of accessory equipment on the straight-away 14-in. mill are considered, it is debatable whether the straight-away or the cross-country mill is the more efficient unit.—M. D. J. B.

Thin Sheets: Hot Mill Technique in Pack Rolling. J. H. Mort. (Iron and Steel, 1951, vol. 24, June 15, pp. 235–241). The author discusses the production of 2–3-ft. wide sheets of 30–33 B.G. in mechanized conventional mills. in which the sheets are reduced to the specified final thickness during the initial hot-rolling process. Consideration is given to the following individual factors: Steel composition, roll dimensions, roll dressing, peripheral speeds, heating facilities, mill personnel, millwrighting and the rolling technique. Formulæ for determining the amount and degree of convexity of a pack and the angle subtended by the 'horned' tail end of a convex pack are derived, and examples illustrating their use are given. Finally, the output and wastage obtained and the efficiency of the process are discussed.—G. F.

The Physics of Sheet Steel. G. C. Richer. (Sheet Metal Industries, 1948, vol. 25, Feb., pp. 303–308; Apr., pp. 707–715; June, pp. 1135–1140; July, pp. 1337–1344; Aug., pp. 1550–1558; Sept., pp. 1763–1768; Oct., pp. 1965–1972, 1978; Dec., pp. 2412–2414; 1949, vol. 26, Jan., pp. 75–80, 86; Feb., pp. 309–314, 318; Mar., pp. 525–526, 528; Apr., pp. 742–746, 750; May, pp. 965–970; July, pp. 1421–1426; Aug., pp. 1661–1666; Oct., pp. 2115–2120; 1950, vol. 27, Feb., pp. 111–115; Mar., pp. 203–207; June, pp. 495–500; Sept., pp. 807–812; 1951, vol. 28, Jan., pp. 19–22, Mar., pp. 223–227; July, pp. 597–602, 608). This concludes a series of articles (*see* Journ. I. and S.I., 1948, vol. 158, Apr., p. 538) in which the author outlines the general nature of the impact of modern physics on problems relating to the production and use of sheet steel, particularly deep-drawing and electrical qualities.—R. A. R.

Steel Strip Experimentally Rolled from Powder. B. M. Pearson. (Iron Age, 1951, vol. 167, Feb. 1, pp. 110–114; Feb. 15, pp. 95–99). This is a translation of a paper by G. Naeser and F. Zirm which appeared in Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 995–1003 (*see* Journ. I. and S.I., 1951, vol. 168, July, p. 324).

Tungsten Carbide Rolls for Cold Rolling Metals. R. T. Beeghly. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 74–78). A brief review is given of the development of tungsten carbide rolls together with a description of how these rolls are manufactured. The method of manufacture, grinding technique, and roll design are considered, after which considerable operating data are given. The advantages and disadvantages of using carbide rolls, and current mill practices and standards, as established by carbide roll users, are discussed.—M. D. J. B.

Rolling of Tool Steels. H. C. Bigge. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 57–65). The author describes all the phases in the production of tool steel as manufactured at the Bethlehem Steel Co. All tool steels are made by the basic electric furnace process, the lower alloy, carbon and carbon-vanadium grades in 28-ton and 50-ton furnaces, and the high-speed, air-hardening, hot-work steels and similar grades in a 7-ton basic arc, top-charged furnace. The methods of casting ingots, stripping, preheating, annealing, forging, and rolling are described in detail. Information on methods of rolling tool and alloy steel rounds and squares is given.—M. D. J. B.

The Continuous Seamless Pipe Mill. J. L. Young. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 53–58). The author discusses the production of seamless pipe with particular reference to the Lorain plant of the National Tube Co. which has a rated capacity of 18,000 tons per month in the size range of 2- to 4-in pipe. Regardless of pipe size, the tonnage rate of the mill is in the region of 40 tons/hr. The advantages of stretch-reducing mills are considered; this type of mill is only economically successful if there is a large demand for a small range of pipe sizes. Ancillary plant is also considered. Technical details of the mills, furnaces, shears, straighteners, piercing mills, conveyor systems, and power consumption are given.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Diesel Electric Locomotives Serve the Steel Industry. R. J. Schroer. (Blast Furnace and Steel Plant, 1951, vol. 39, Apr., pp. 452–453, 456). The general operating conditions of diesel electric locomotives are reviewed. The author points out that the simplicity and ruggedness of the two-axle locomotive and the box-type understructure which may be used to full advantage, gives it two distinct advantages over the four-axle type. Articulated truck locomotives and miscellaneous designs are discussed.—J. P. S.

Power Generation by Gas Turbines. A. G. Mellor. (Blast Furnace and Steel Plant, 1951, vol. 39, May, pp. 566–570). Several types of gas-turbine unit are described and compared. The operation of gas turbines is discussed and the generating station is considered. Gas-turbine stations are compared with diesel stations and steam-electric stations. The author concludes by suggesting that the most probable applications of gas turbines for power generation are as base load units on small and medium sized power systems, for peak loads on similar systems, as end-of-line generating plants on some systems, as mobile emergency power plants, and that the heat available in the exhaust gases could be used in the heat cycle of an adjacent steam-electric generating system.—J. P. S.

An Interesting Application of the Torsion Bar on Guillotine Shears. A. G. Ligier. (Métallurgie, 1951, vol. 83, Apr., pp. 267–269). The high operating speeds of Grimar guillotine shears, the considerable inertia of the moving parts, and the degree and frequency of displacement offer great mechanical possibilities for the application of torsion bars for counterbalancing the cutter-bars and the automatic taking up of play. Theoretical and practical advantages and the system of assembling the bars are described.—R. S.

Billet Shears. (Iron and Steel, 1951, vol. 24, June, pp. 229–231). The new 5-in. billet shear made by The Head Wrightson Machine Co., Ltd., is described.—R. A. R.

Mechanical Engineering in the Iron and Steel Industry: A Review of Recent Developments in Equipment. W. F. Cartwright. (Institution of Mechanical Engineers: Iron and Coal Trades Review, 1951, vol. 162, June 22, pp. 1441–1445). The author discusses the rapid development of the iron and steel industry in the last 50 years, which has had two main aspects: (1) Quality improvement, largely resulting from metallurgical improvements; and (2) increase in output, made possible by the application of mechanical engineering principles. Prime consideration is given to the second aspect. The use of hydraulic power is also discussed.—G. F.

Preventive Maintenance for Electric Overhead Cranes. H. C. Mullings. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 76–82). The author considers the operating conditions of steelworks cranes; these are varied and almost always severe. The first two steps in preventive maintenance are an adequate building structure and a good design of crane fitted with adequate motors. The author then discusses the erection and testing of cranes, organization of maintenance staff, inspection, economics of maintenance, planning and scheduling of repair jobs, and the modernization of equipment to keep pace with changing working conditions. The abuses to which cranes are submitted are considered. Many of these could be avoided by proper education and training of crane operators. The function of lubrication in preventive maintenance is stressed. Planning and recording of repairs, stocks of spares, and safety precautions are dealt with.—M. D. J. B.

Grounding Practice at Inland Steel. V. E. Schlossberg. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 77–79). A description is given of earthing installations at Inland Steel and methods of ensuring adequate protection against lightning are discussed. To ensure that overhead conductors are free from lightning strokes, and motors and transformers are free from lightning damage, overhead ground wires properly earthed at each tower with lightning arrestors and surge capacitors at each motor should be installed.—M. D. J. B.

Fuses and Circuit Breakers for Short Circuit Protection. K. S. Kuka. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 108–112). This paper explains in general terms the phenomenon of arc interruption in an electrical circuit and the behaviour of small circuit breakers and fuses under short-circuit conditions so that it is possible to understand and appreciate the best protection that can be effected economically. The physical phenomena of circuit interruption are explained in detail as well as the mechanism of D.C. and A.C. arc extinction. The operation of fuses under short circuit and the interrupting ability of fuses and circuit breakers are discussed together with interrupting rating. For adequate protection the maximum fuse that should be selected is about 3½ times the current rating of the overload relay.—M. D. J. B.

LUBRICANTS AND LUBRICATION

Rolling Solutions for Speciality Steels. M. L. Bible. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 91–93). The author describes rolling lubricants and coolants with special reference to stainless steels. The importance of maintaining a stable solution as a guarantee to high-quality finish is stressed. It is suggested that a good finish-rolling lubricant consists of about 85% of mineral spirits of a low-solvency material, 5% of a heavy viscous oil, and 10% of 'fatty' materials having a Saybolt viscosity at 100° F. of about 36 sec.—M. D. J. B.

Molybdenum Lubricant Proves Itself in Tough Tests. A. Sonntag. (Iron Age, 1951, vol. 167, Feb. 8, pp. 91–93). Tests have been carried out with molybdenum disulphide as a lubricant at pressures of 10,000 lb./sq. in. which show it to be superior even to colloidal graphite in water. It appears to be unaffected by low temperature and while it oxidizes at elevated temperatures the rate of oxidation in air is not serious below 750° F.—A. M. F.

Metal Drawing Lubricants for Wire, Tubing, and Sheet Steel. W. A. Smigel and H. G. Verner. (Iron and Steel Engineer, 1951, vol. 28, Apr., pp. 97–102). Progress in metal-drawing lubrication is reviewed and practical suggestions on the selection and use of lubricants for the drawing of wire, tubing, and sheet steel are made. The physical and chemical characteristics and the factors affecting the selection of lubricants for dry and wet wire drawing are considered in detail. Sodium and metallic soaps are considered as well as straight soap lubricants, emulsion-type lubricants, petroleum-oil lubricants, wire-drawing grease lubricants; and lime substitutes. Methods of control for tube drawing are discussed.—M. D. J. B.

Lubrication in Steelworks Plant. H. J. Knight. (Sheet Metal Industries, 1951, vol. 28, Mar., pp. 213–218, 227). The author selects for discussion the following major items: Rolling-mill bearings, gears, and power equipment. The required features of a good roll-neck bearing grease are listed and discussed, and the properties desirable in bearing metals are also considered. Fabric, roller, and oil-flood bearings are next considered, and the greases and oils again discussed. Oils suitable for gear systems, steam turbines, and electrical equipment are specified, and the uses and advantages of centralized oil and grease systems are outlined.—P. M. C.

WELDING AND FLAME-CUTTING

What is Weldability? H. G. Geerlings. (Lastechniek, 1951, vol. 17, Feb., pp. 17–71). [In Dutch]. The author discusses the factors to be considered in formulating a definition of weldability. An account of the work of Committee IX of the International Welding Institufe on weldability tests is given.—R. S.

A Survey of Modern Theory on Welding and Weldability. D. Séférian. (Sheet Metal Industries, 1950, vol. 27, Mar., pp. 241–253; Apr., pp. 339–346; May, pp. 435–444; Aug., pp. 727–730, 732; Nov.–Dec., pp. 935–949, 952: 1951, vol. 28, Jan., pp. 59–72, 96; June, pp. 553–565). Continuation of a series of articles (*see* Journ. I. and S.I., 1950, vol. 166, Dec., p. 374). The March instalment deals with 13 kinds of welding fault. Weld inspection is described, particular attention being given to supersonic and X-ray techniques. A survey is made (April issue) of the phenomena affecting and defining weldability. Chemical changes, absorption of gases, precipitation of compounds in solid solution, and eutectic transformations are all discussed in detail. Structural modifications are discussed (May issue), and then follows a long discourse on the effect of heat on the metal in the fusion zone and the parent material. Defining and determining weldability are also dealt with. A comprehensive discussion of both technical and structural weldability tests for various materials is presented (August issue). Details are given of test procedures and specimen dimensions for many types of test. The author deals (Nov.–Dec. issue) with the weldability of plain carbon steels, the metallurgical theory being discussed with reference to the iron–carbon diagram. The influence of the other usual steel constituents on weldability, and the structural investigation of welded joints are all considered with reference to plain carbon steels. The weldability of alloy steels is considered (Jan. issue). In particular, the techniques employed in welding the following types of steel are described: Copper–chromium steels for bridge and structural engineering; chromium–molybdenum steels for aircraft construction; plain chromium steels; Ni–Cr–Mo self-hardening steels; and finally various stainless types including 18/8. The June issue is devoted to the welding of aluminium and light alloys.—P. M. C.

A Hundred Years of Progress and Development in Metal Joining Processes. F. A. Fox and A. J. Hipperson. (Sheet Metal Industries, 1951, vol. 28, May, pp. 465–472). A general review is given of joining processes from their early beginnings in 1850. The development of arc, gas, and resistance welding is outlined, and diagrams of early machines and equipment are shown. Applications such as soldering and brazing are dealt with, and modern methods including argon-arc welding and multipoint spot welding are described. There are 38 references.—P. M. C.

Welding or Casting? E. Piwowarsky. (Giesserei, 1951, Special Issue 'Konstrukteur und Giesser,' p. 85). The respective merits of welded and cast construction are discussed, with references to American literature. The author concludes that welded large machine parts, frames, and housings cost three times as much as when cast. Advantages of welded construction, though recognized, are not examined. J. G. W.

Molybdenum-Containing Stainless Steels. (Maquinas e Metais, 1950, May, pp. 3–5). [In Portuguese]. The resistance, spot, and projection welding of 18/8 and 25% nickel steels containing 4·5% molybdenum and having low carbon contents is discussed.—R. S.

Deep-Penetration Arc Welding. V. Machado de Carvalho. (Maquinas e Metais, 1951, Apr., pp. 4·5). [In Portuguese]. The application of deep-penetration welding is described. Electrode consumption and costs are compared for normal electrodes and Quasi-Arc Weldeep electrodes. Deep penetration is obtained by using an arc of high potential. Precautions to be taken are noted.—R. S.

Influence of Bead Length per Electrode on Root Penetration. (Lastechniek, 1951, vol. 17, Mar., pp. 45–46). [In Dutch]. Root penetration, sometimes appearing in fillet welding, is mainly due to the bead length and size of electrode. More than 100 tests were made in which the length of arc, current, and angle between the electrode and the work were maintained constant. It was found that maximum root penetration was related to a much greater bead length than was commonly supposed.—R. S.

Examination of Pipe Welds by Means of Radioisotopes. B. N. M. Bruls. (Lastechniek, 1951, vol. 17, May, pp. 70–73). [In Dutch]. Electric welds in a 45-km. long high-pressure gas pipe 10 in. in dia. were examined. An iridium isotope was introduced through a ⅜-in. hole in the pipe. About 25 welds per day can be checked.—R. S.

Electric Welding in an Inert Gas Atmosphere. M. Andre Brizard. (Instituto de la Soldadura, Publication No. 18, 1951, pp. 7–19). [In Spanish]. After describing the development of inert gas welding, the author studies the arc in an atmosphere of argon, using a refractory electrode of wolfram and a fusible electrode generally of the same composition as the parent metal. Feeds of argon and current, using both types of material are discussed. Finally, argon spot welding is described. Argon arc welding with fusible electrodes gives deep penetration, while depositing considerable quantities of weld metal in a short time. It is not used for material thinner than 5 mm.—R. S.

The Efficiency of Electric Welding in Steel Constructions from the Constructor's Point of View. W. Gerritsen. (Lastechniek, 1950, vol. 16, Nov., pp. 170–176). [In Dutch]. The properties of bending and torsional strength and of damping in structures are discussed. Welding and riveted structures are compared as regards economy of design. The

necessity of close co-operation between welder and designer is emphasized. Points for consideration in designing a welded structure are stated. Practical examples of efficient design for welded structures are described.—R. S.

Rail Welding Equipment of the Dutch State Railways at Utrecht. N. Beukenkamp. (Lastechniek, 1950, vol. 16, Dec., pp. 187–192). [In Dutch]. The type of automatic welding machine for welding long rails is described. Particulars of testing welded rails and the microstructure of the welds are discussed.—R. S.

Basic-Coated Arc Welding Electrodes. D. Séférian. (Société Française de Métallurgie : Iron and Coal Trades Review, 1951, vol. 162, June 15, pp. 1369–1372). In this paper the author attempts to elucidate the main properties of basic-coated arc welding electrodes by the application of the laws of physical chemistry. The results show that basic coatings permit a range of electrodes with static tensile tests of 50–100 kg./sq. mm., and that basic coats are necessary for alloy steel work. Dephosphorization and desulphurization are also assisted by basic coatings, and the resulting grade of the weld metal favours high test results in the welded assemblies. The major disadvantage of the basic coating is its great sensitivity to moisture.—G. F.

Recent Developments in Fluxes for Welding. W. M. Conn. (Journal of Metals, 1951, vol. 191, Feb., pp. 98–99.) The author briefly discusses the preparation and properties of the three principal groups of fluxes which have been developed for submerged-arc welding, and which are based on the use of natural clay, glass, and mullite respectively. A ceramic flux is said to permit the use of a higher voltage in welding ; less flux is required and it permits the welding of rusty or moist steel without further preparation.—G. F.

Die Welding by the Metal Arc. A. R. Butler. (Welding Engineer, 1951, vol. 36, June, pp. 28–31 ; July, pp. 32–35). The repair and fabrication of hot and cold tools can be done with the metallic arc, preferably D.C. Electrodes may be all types of tool steel and high-alloy rods. Nickel rods are used for preliminary building up cast-iron tools. Preheating, welding technique, cooling, and tempering are discussed. The electrode should match the heat-treatment of the tool ; *i.e.*, water, oil or air hardening or hot working. Details are given of the procedure for the repair and fabrication of all types of tool-steel die. Choice of electrode, preparation of tool, pre-heat for various tool steels, and depositing technique are described. Warping is offset by preheating and peening, and final heat-treatment relieves stresses and refines the grain structure.—M. R.

Wear Tests Performed on the Machine for Testing Wear by Minerals. H. Timmerbeil. (Giesserei, 1951, vol. 38, Feb. 8, pp. 52–54). A special testing machine is described and illustrated and tests are described in which specimens coated by means of hard-metal electrodes and the abrasion-resistant electrode E4500 Schwarz were compared for wear, the abrasive medium being drysilver sand. The Schwarz electrode proved superior. This was followed by steel shot-blast tests comparing hard metal and cast-iron blades. The former lasted for 3000–4000 hr. as against 3½ hr. for cast iron.—J. G. W.

Automatic and Semi-Automatic Fusion Welding. N. A. Skov. (Dansk Teknisk Tidskrift, 1950, vol. 74, Nov., pp. 415–418). [In Danish]. The fundamentals of automatic fusion welding are given, followed by a few examples of American semi-automatic applications.—B. S. E.

Rational Welding of Pressure Vessels. E. Hågå. (Dansk Teknisk Tidskrift, 1950, vol. 74, July, pp. 249–255). [In Norwegian]. The rationalization measures in the quoted examples of welding of pressure vessels for the whaling and chemical industries include automatic welding by introducing a Unionmelt machine with large-diameter electrodes, and horizontal welding.—B. S. E.

Resistance Welding As a Rationalizing Factor in Industry. B. Andersson. (Dansk Teknisk Tidskrift, 1950, vol. 74, Aug., pp. 283–288 ; Sept., pp. 325–330 ; Oct., pp. 377–382). [In Swedish]. Resistance welding methods are broadly outlined, and illustrations of typical Allmänna Svenska Elektriska Aktiebolaget (ASEA) welding machines are shown. Finally, examples of cost reductions achieved by introducing resistance welding to replace arc welding are given.—B. S. E.

An Explanation of Hot-Cracking of Mild Steel Welds. E. C. Rollason and D. F. T. Roberts. (Transactions of the Institute of Welding, 1950, vol. 13, Dec., pp. 129r–132r : Australasian Engineer, 1951, May 7, pp. 85–87). Hot cracks in mild-steel welds are intercrystalline tears occurring at elevated temperatures, and in the regions of the weld metal which solidify last. It is suggested that such cracks are due to the segregation of FeS, which has a low melting point (approx. 1200° C.). The presence of manganese, which promotes the formation of manganese-rich sulphides of high melting point, reduces the tendency to hot-cracking. Mn/S ratios of 15 or over are desirable in welding rods if this trouble is to be eliminated. The minor influences of phosphorus, silicon, carbon, and nickel are also discussed.—P. M. C.

Welding and Metals in Shipbuilding. C. F. Tilson. (Australian Institute of Metals : Australasian Engineer, 1951, May 7, pp. 60–64). The initial development of welding methods in ship construction is discussed. The author then describes the development of the Broken Hill Proprietary shipbuilding yard at Whyalla, S. Australia, the welding equipment available, and the extent to which welded construction is being employed.—P. M. C.

Stainless Arc Welded without Columbium. R. K. Lee. (Steel, 1951, vol. 128, Mar. 19, pp. 71–72). **Arc Welding Stainless Steel without Columbium.** R. K. Lee. (Welding Journal, 1951, vol. 30, May, pp. 447–448). Corrosion resistance without the use of columbium can be obtained in welds if stainless steel of max. 0·03% carbon is used in conjunction with extra-low carbon electrodes. At this carbon level there is no appreciable carbide precipitation after short-time exposure to temperatures of 800° to 1500° F.—A. M. F.

Stud Welding to Ferrous and Non-Ferrous Metals. T. L. Hufert, P. F. Powder and J. Nater. (Product Engineering, 1951, vol. 22, Mar., pp. 89–91). Stud welding of ferrous and non-ferrous metals and alloys is a proved and economical method of fabrication, often resulting in design simplification and product improvement. In this article the answers to numerous questions that may be encountered when considering this particular method of joining are given.—A. M. F.

Butt Welding Wire and Rod Economically. H. J. Chamberlain. (Wire and Wire Products, 1951, vol. 26, Feb., pp. 146–147). A new fully automatic butt welder for welding wire and rod up to ⅜ in. in dia., coping saws, jig and band saws, and extensions to drills, taps, reamers, bits, is described and illustrated.—J. G. W.

Some Considerations in the Joining of Dissimilar Metals for High-Temperature High-Pressure Service. O. R. Carpenter, N. C. Jessen, J. L. Oberg, and R. D. Wylie. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 809–857). This comprehensive work studies the reasons for failures in dissimilar metal welds under conditions of high temperature and pressure. The fundamental causes of failure of a weld between ferritic and austenitic materials are expansion and operating stresses ; secondary causes such as oxidation, fatigue, carbon migration, and poor welding techniques accelerate these failures. In an attempt to find remedies, work was performed on welding techniques and developments. Stabilization of carbides in the ferritic materials was also studied. Many test results are included.—T. E. D.

Welds between Dissimilar Alloys in Full-Size Steam Piping. R. U. Blaser, F. Eberle, and J. T. Tucker, jun. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 789–808). Factors affecting the safe operation of ferritic–austenitic weld joints in steam piping of large diameter were studied by means of a simulated proof test by the Babcock and Wilcox Co., Ohio. The specimen consisted of a 10¾-in. dia. section of 2¼Cr–1Mo steam piping welded to 18Cr–8Ni–Cb wrought and 16Cr–13Ni–2MoCb cast materials, using 19Cr–9NiCb welding electrodes. Cracks were detected at the edge of the weld joint, in the 2¼Cr–1Mo pipe, after 4631 hr. at 1100° F. and 1500 lb./sq. in. pressure, involving 47 week-end shutdowns to atmospheric conditions. Metallurgical examination showed that the factors contributing to failure were residual stresses from the welding operation, operational stresses due to internal pressure, stresses due to differences in thermal expansion of the ferritic and austenitic materials, accelerated creep, intergranular stress-oxidation, and weakening of the ferritic metal adjacent to the fusion zone due to carbon migration into the austenitic weld material.—T. E. D.

How Dodge Hardfaces Gear Forging Dies. J. C. McComb. (Steel Processing, 1951, vol. 37, May, pp. 231, 257). Areas of forging dies which wear excessively are faced with an alloy containing 1% C, 4·5% W, 28% Cr, and 62% Co. After removing $\frac{1}{16}$ in. of the die surface by rough machining, the

block is heated to approximately 950° F. and the alloy deposited by electric welding rod. After slow cooling, the die is machined with tungsten carbide tools.—P. M. C.

Welding Characteristics of Open Hearth and Bessemer Seamless Steel Pipe. A. B. Wilder, W. B. Kennedy, and F. W. Crouch. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 763–780). Deoxidized acid-Bessemer, silicon-killed and silicon–aluminium-killed basic open-hearth steel pipes in as-rolled condition were investigated in connection with their welding characteristics. The properties of girth welds and laboratory bead welds were studied. Tension and bend tests were made on the girth welds, and a new weldability test, the weld bead flattening test, for tubular products is described. The internal structure and hardness of the girth and bead welds, and the advantages of multi-pass welding are discussed. Impact properties of the girth weld were also investigated. Lower hardenability, lower bead weld hardness, and less cracking susceptibility were observed for Bessemer steel pipe than for open-hearth pipe. Bessemer and silicon–aluminium-killed open-hearth pipe had higher impact strength at low temperatures, less martensite and under-bead cracking in the small weld bead, and lower hardenability than silicon-killed steel.—T. E. D.

The Proper Application of Electric Welding in Steel Constructions. W. Gerritsen. (Ossature Métallique, 1950, vol. 15, Sept., pp. 404–407). The advantages of welding over riveting as a method of fabrication are emphasized. They include reduction in weight, simplification in design and assembly, and elimination of rivet holes which are a source of weakness ; but the tension caused by shrinkage is a problem. The relationship between weight and rigidity for beams of various cross-sections is illustrated graphically. Examples of assemblies lending themselves to the welding technique are given. Caissons provide an opportunity for both welding and riveting.—N. McE.

Jobs You Can Do With Bronze Electrodes. F. E. Garriott. (Welding Engineer, 1951, vol. 36, July, pp. 20–24). Bronze electrodes are used for joining metals and for overlays. Aluminium–bronze electrodes giving deposits of 200 to 300 Brinell hardness are used for such components as pulverizing mill shafts, cable sheaves, pulley sheaves, gear teeth, etc. The technique and economies are described.—M. R.

Oxy-Acetylene and Electric ' Solder ' Welding at Low Temperatures. G. M. A. Blanc. (Lastechniek, 1951, vol. 17, Jan., pp. 12–15). [In Dutch]. A distinction is drawn between ' melting point ' (of the weld metal) and ' welding point ' (the temperature to which the parent metal must be brought so that the weld metal can adhere. In fusion welding, weld metal and parent metal are practically identical and both are brought to the same temperature. (*i.e*, the ' melting point '). In low-temperature welding, the weld metal has a lower melting point than the parent metal and welding takes place at a lower temperature than the melting point of the weld metal. Thus, welding occurs at a temperature far below the ' welding point.' This is the main characteristic of ' solder welding.' Cast iron melts at about 1200° C. Castolin No. 14 (a synthetic cast-iron alloy for ' solder welding ' cast iron) welds at 760° C. The welding of the two metals occurs below the melting point of either. The advantages of this welding are outlined.—R. S.

Oxy-Acetylene and Oxy-Propane Flames Applied to the Process of Cutting. R. Credeville. (Journal du Four Electrique, 1951, vol. 60, May–June, pp. 60–64). Comparison has been made of the economics of acetylene and propane for use in flame-cutting. The author states that for a given metal thickness more oxygen was required using propane than acetylene and that the rate of cutting is also greater with the latter gas.—B. G. B.

MACHINING AND MACHINABILITY

Hot Metal Machining. S. Tour. (Metal Progress, 1951, vol. 59, June, pp. 793–794). This is a description of a method of more rapidly machining steels that are usually difficult to deal with. The stock is heated by high-frequency induction, just ahead of the tool, to say 1000° F. This results in a lowering of the tensile strength and so of the work needed for cutting. No coolant is used on the carbide tool bits, but it is applied to the stock after the cut to lessen the expansion against the lathe tailstock.—E. T. L.

A Contribution to the Study of Tool Cutting Capacity. M. Cociglio. (Metallurgia Italiana, 1951, vol. 43, May, pp. 170–176). The cutting capacity of a material is a complex quantity depending on many physical properties of the material, one being the resistance to wear at high temperature. The author stresses the desirability of being able to express cutting capacity by a simple number and of finding a practical method of assessing this number. After critically reviewing many methods of evaluating cutting characteristics, a new method based on rate of wear measured over a fixed length of cut at constant speed is proposed.—M. D. J. B.

Some Features of The Machinability of Steels. L. Locati and T. Natale. (Metallurgia Italiana, 1951, vol. 43, May, pp. 164–169). The authors described a method of measuring the machinability of steels based on the temperature reached at the cutting edge of the tool. A coefficient of machinability may be determined for every steel. This method is applied to case-carburized steels and the coefficient of machinability is justified on metallurgical grounds. It is shown also how machinability can be considerably improved by appropriate heat-treatment.—M. D. J. B.

Recording Methods in Metallurgical Problems of Surface Finish. L. Locati and B. Bianchi. (Metallurgia Italiana, 1951, vol. 43, May, pp. 176–179). The question of surface finishes has for some time past been the object of standardization. This paper describes apparatus developed in Italy for the industrial control of finishes. A review is given of metallurgical problems, in which surface finish plays a determining part. Amongst other problems, the authors discuss : (1) Characteristics of metals giving good finishes ; (2) types of oil to use with cutting tools ; (3) problems of surface creep ; and (4) the surface of steel strip.—M. D. J. B.

Surface Characteristics. E. G. Bildsöe and C. C. Fabricius. (Dansk Teknisk Tidskrift, 1950, vol. 74, May, pp. 140–143). [In Danish]. Roughness, surface waving, and scratch are defined, followed by a presentation of the principles of determining the surface characteristics by means of the tracer-pin profilometer.—B. S. E.

Improvement of Machinability in High-Phosphorus Gray Cast Iron—Part II. W. W. Austin, jun. (American Foundrymen's Society, 1951, Preprint No. 12). This paper reviews additional results of an investigation carried out at the Southern Research Institute. Foundry-scale applications of the desulphurizing zirconium-addition treatment for machinability improvement in high-phosphorus grey iron are described and performance data including cost estimates and results of tool life machinability tests are presented. The results indicate that significant improvement in machinability may be accomplished through application of the proposed treatment under foundry operating conditions. While best results were obtained by desulphurization with calcium carbide in the basic-lined cupola followed by ladle additions of zirconium ferrosilicon, published results indicate that satisfactory sulphur elimination may also be obtained with caustic soda employing a special reladling technique. The cost of the zirconium treatment utilizing caustic soda desulphurization is estimated at $2.75 per ton of treated iron.—F. C. P.

Centreless Turning of Bars, Billets, and Tubes. W. Siegerist. (Iron and Steel Engineer, 1951, vol. 28, May, pp. 67–74). The centreless turning and peeling of bars, billets, and tubes consists of the operations necessary to remove the surface of a bar or tube to a desired depth. Descriptions are given of self-feeding centreless bar turners, roll-feed hydraulic-grip centreless bar turning machines, push-draw turners with carbide tools, and hydraulic billet peelers. Technical and operational data are given and diameter tolerances and coolants discussed.—M. D. J. B.

Production Techniques as Defence Reserves. D. F. Galloway. (Engineer, 1951, vol. 191, May 18, pp. 639–644). This paper reviews the production capacity of Great Britain in the light of the new defence programme. Production capacity depends on material supplies, machines and tools, power supplies, labour, and production techniques. The savings resulting from improved production techniques and the cost of establishing the latter are considered in detail. A practical programme to establish optimum conditions for machining and forming materials, securing widespread and prompt application of the results obtained, and establishing standard methods of assessing machinability and formability of a selected range of ferrous and non-ferrous materials is put forward.—M. D. J. B.

New Method Machines Sintered Carbides, Sintered Borides, Hardened Tool Steels. A. S. Cohan. (Journal of Metals,

1951, vol. 3, Mar., pp. 216–217). A brief description is given of a new machining method, known as the Cavitron process, for cutting, threading, drilling, forming, and other machining operations on hard and brittle materials. The method employs ultrasonic vibrations with a blunt tool in the shape of the cut or hole required, with a stream of inexpensive commercial abrasive in a liquid carrier. The method leaves an excellent surface finish, and as it does not heat the work the material is not affected metallurgically or chemically.—G. F.

CLEANING AND PICKLING

The Use of Steel Shot In Airless Cleaning of Forgings. N. S. Mosher. (Drop Forging Association : Steel Processing, 1951, vol. 37, Apr., pp. 175–178, 205). This article is a general review of the economics of the shot-cleaning process. The recent American standardization of shot sizes and testing methods is reviewed, and the importance of maintenance of machines and shot separators is emphasized.—P. M. C.

Plating Hints. T. M. Rodgers. (Metal Industry, 1951, vol. 79, July 6, pp. 6, 7). The author emphasizes that faulty cleaning and pretreatment are responsible for a large percentage of defective deposits in the plating industry. A brief review is given of standard degreasing methods, followed by details of both soak and electrolytic cleaning processes. Recommended compositions of several alkali-type solutions for cleaning are given, and a brief description is given of a simple titration procedure for checking the strength of cleaning solutions.—P. M. C.

A New Processing Scalebreaker. J. I. Greenberger. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 95–101). The author traces the development and background of the processing scalebreaker, points out its engineering principles, and shows its very real advantages when applied to pickle-line operation, particularly in terms of savings by increasing the speed of pickling, and also in acid consumption. The author points out the extreme flexibility and real operating control which is now available to the operator, and suggests other possible applications for equipment of this type.—M. D. J. B.

Mechanism of Electrolytic Polishing of Metals. W. J. McG. Tegart and R. G. Vines. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 243–250). Polishing occurs by the simultaneous formation of a liquid viscous layer of the products of electrolysis and of an underlying oxide film, and the relative importance of these two processes has been studied. The theory advanced explains polishing with both high and low current densities, and chemical polishing may be an extension of the same mechanism.—A. G.

The Electrolytic Polishing of Steel and Alloy Steels and Its Industrial Application. W. Eilender, R. Mintrop and R. Au. (Metalloberfläche, 1950, vol. 2, June, pp. B81–B88). A review is given of the literature on electrolytic polishing in its industrial application to steel. There are 39 references.—O. H. G.

The Electrolytic Polishing of Steel. J. Heyes and W. A. Fisher. (Metalloberfläche, 1950, vol. 4, Mar., pp. A38–A44). The paper reports experiments on : (1) Rise in temperature of steel specimens during electrolytic polishing. An iron–constantan thermocouple was attached to one side of a 2-mm. square strip of soft iron. The side with the thermocouple was insulated and the opposite side (9 sq. cm. area) was made the anode in a water-cooled cell containing a constantly stirred electrolyte of 185 c.c. perchloric acid (density 1·61), 765 c.c. acetic anhydride, and 50 c.c. water. It was found that on increasing the current density beyond 0·03 amp./sq. cm. there was a sudden increase in the potential difference between cathode and anode associated with the appearance of the brown viscous layer previously observed by Jacquet, and with the onset of polishing action. The rise in potential difference was accompanied by a similar rise in the temperature difference between anode and electrolyte. This temperature difference was 2·5, 27, 45 and 69° C. at current densities of 0·03, 0·04, 0·1, and 0·3 amp./sq. cm. respectively when using fresh electrolyte. (2) The effect of this temperature rise on the quality of the surface produced by electrolytic polishing on samples of 11 heterogeneous alloy steels. In each case it was found that the higher the current density above the necessary minimum the rougher the surface. This is attributed to etching caused by the high temperature of the anode. All but one of the steels (one containing 1·6% C and a total of 24% of W, Cr, V, and Co) gave satisfactory results with sufficiently low current densities. (3) The effect of elecrolytic polishing on the bending fatigue strength of a chromium–vanadium steel. Unannealed specimens gave worse results after electrolytic than after mechanical polishing, due to the removal of surface stresses by the former. Annealed specimens of the steel (and of a molybdenum steel) gave the same values regardless of whether they had been electrolytically or mechanically polished.—O. H. G.

Degreasing by Leaching in Metal Processing. R. Justh. (Metalloberfläche, 1950, vol. 4, May, pp. A72–A76). The article discusses the principles underlying the methods of degreasing used by the metal-working industries.—O. H. G.

Improved Pickling : Economical Working by Means of Ion Exchange. T. R. E. Kressman. (Iron and Steel, 1951, vol. 24, May, pp. 181–182). This article briefly describes a phosphoric acid pickling process used in America which successfully avoids many disadvantages of sulphuric acid pickling. An ion-exchange method of removing the iron from the phosphoric acid pickling liquors is involved and it is claimed that the process is cheaper than sulphuric acid pickling. The system of operation of the purification process is described and the resulting advantages of this pickling method are indicated.—G. F.

Rotary Pickling Plant for Handling Hot-Rolled Strip in Coils. E. W. Mulcahy. (Sheet Metal Industries, 1951, vol. 28, May, pp. 435–438). The plant here described performs the unique operation of opening and closing hot-rolled coiled strip of all sizes up to 14 in. wide and 42 in. in dia. during the process of pickling, without manual preparation. The coils are loaded into specially designed circular cages which rotate on a horizontal axis one-third immersed in the acid pickling solution. The coils, which are located vertically, are rotated by rolling on the inside perimeter of the rotating cage, and when the cage rotation is contrary to the windings of the coil, the coil opens strand by strand. Reverse rotation of the cage causes the coils to rewind. A diagram of the plant layout and details of the procedure are given.—P. M. C.

Surface Active Agents and Pickling Brittleness. C. A. Zapffe and M. E. Haslem. (Wire and Wire Products, 1951, vol. 26, Feb., pp. 127–133). Research on the effect of pickling inhibitors on the hydrogen embrittlement of steel has been continued using SAE 1020 carbon steel and AISI 440-C stainless-steel wire $\frac{1}{8}$ in. in dia., pickled in a standard 10% H_2SO_4 bath, with and without inhibitors, and with 14 different surface-active agents, representing anionic, cationic, and non-ionic groups, the last containing a series of polyethylene oxides of increasing molecular weights from 200 to 6000. Embrittlement was measured in a special 180° bend test. All anionic reagents were without effect on embrittlement. Of three cationic reagents two reacted so strongly with the acid that their study was abandoned. The third, Catylon D (manufactured by Hart Products Co.), a mixture of amine salts of a fatty acid amide, reduced the tendency to embrittlement of the carbon steel. Most of the non-ionic reagents decreased the embrittlement of the carbon steel, the effect increasing with the molecular weight in the use of the polyethylene oxides. All these reagents tended slightly to increase the embrittlement of the stainless steel. When used in combination with the inhibitor Rodene 250, which is the only inhibitor known to reduce embrittlement of stainless steel, the mixtures had an erratic, but on the whole beneficial, effect on the embrittling action of the acid. The surface-active agents likewise modified the action of the inhibitor Rodene 81, which alone aggravates embrittlement, on the carbon steel. Finally, the addition of a proprietary foaming compound to an inhibiting bath aggravated embrittlement.—J. G. W.

The Treatment of Liquor from Continuous Strip Pickling Lines. J. Pearson. (Sheet Metal Industries, 1951, vol. 28, June, pp. 501–516). Modern high-speed strip rolling mills require fast pickling of the hot-rolled strip if production is to flow smoothly. This necessitates pickling baths of high activity which, in turn, implies that enormous volumes of spent liquor of high acid strength will be produced. The author shows how these volumes may be calculated in advance from a knowledge of the desired operating conditions. Methods have been devised by which recovery of acid by evaporation and crystallization, and by regeneration from ferrous sulphate, may be effected. These methods are reviewed, and the researches of B.I.S.R.A., leading to the decision to build a pilot scale ' Autox ' plant for the production of sulphuric acid from ferrous sulphate, are described. There are 27 references.—P. M. C.

PROTECTIVE COATINGS

Automatic Barrel Plating: New Canning Plant at the British Screw Co., Ltd. (Iron and Steel, 1951, vol. 24, June, pp. 217–220). A detailed description is given of the layout and operation of a new automatic barrel zinc-plating plant designed and supplied by W. Canning and Co., Ltd. for the treatment of screws, bolts, and nuts at the works of the British Screw Co., Ltd., Leeds. The plant is entirely modern and is specially designed to combine good protection with low operating costs.—G. F.

Application and Properties of Some Coatings on Iron and Steel. P. Bang. (Dansk Teknisk Tidskrift, 1950, vol. 74, Sept., pp. 297–322). [In Danish]. This is a short summary of some ways of obtaining protective surface coatings, namely phosphatizing, chromizing, oxidizing, hot dipping, cementation, spraying, and electrolytic galvanizing.—B. S. E.

Continuous Electroplating Effects Operational Economy. D. Reebel. (Steel, 1951, vol. 128, Feb. 19, pp. 64–66). The continuous processing cycle for electroplating and phosphatizing of small stamped fastening devices used by Shakeproof Inc., Elgin, Ill., is described. Vibratory feeders and automatic under-and-over weigh scales are important features of the plant.—A. M. F.

Modern Electroplating Plant. A. F. Brockington. (British Engineering, 1951, vol. 33, May, pp. 1086–1092). The paper deals with the equipment for plating with nickel, chromium, silver, gold, brass, and copper. The following parts of the plant are explained: A plate and cloth type press for pressure filtration, 'round about' type of automatic plating plant, the Rotamatic semi-automatic plating tank with pressure filtration, the motor-driven midget plating barrel with perforated basket, a range of three self-contained open-ended plating barrels, fully automatic equipment for bright nickel and chromium-plating car parts, and automatic barrel-type plating equipment for small repetition parts. In premises where the class of work is very varied, semi-automatic plant such as the Rotamatic vat, is often installed. Another example of the semi-automatic equipment is the Rotary chromium vat.—E. T. T.

A Modern Electroplating Shop. (Sheet Metal Industries, 1951, vol. 28, Apr., pp. 380–383). This is a short description of the new building recently completed at the Chippenham Works of the Westinghouse Brake and Signal Co., Ltd. Two main sizes (100 and 200 gal.) of vat have been installed, and barrel-plating equipment ranges from 1-pint work capacity to 4 gal. The metals which can be deposited are nickel, cadmium, tin, copper, and chromium.—P. M. C.

The Properties of Sprayed Metal Coatings. J. Grilliat. (Métaux et Industries, 1950, No. 1, pp. 14–23: Electroplating, 1951, vol. 4, Jan., pp. 13–15, 23). The properties of sprayed metals are compared with those of the same metals rolled. Micrographic study reveals the fine grain structure within the coarse structure of flattened droplets. X-ray examinations show that there is little strain in the crystals of aluminium and zinc deposits. The thermal expansion curves in steels show the effects of fritting at 500° C., and this is confirmed when the electrical resistance is measured at various temperatures. The density is usually about 10% lower than that of the rolled material. The Brinell hardness is increased, the compressibility is less, and the shear strength is also quite high, but the tensile strength and ductility are lower. All the mechanical properties depend on whether measured along or across the direction in which the spray passed. Reheating diminishes most of the effects, which can be attributed to inclusions of gas and oxide.—N. McE.

The Surface Quality of Hard Chromium Plated Parts. W. Eilender, H. Arend, and H. W. Dettner. (Metalloberfläche, 1950, vol. 4, May, pp. A69–A72). Samples of a plain carbon steel, a case-hardened steel and of a silver steel were hard chromium plated, the surface having first been treated by electrolytic polishing, machine grinding, hand polishing, or machining. The plating increased the surface roughness as determined by optical methods. Electrolytic polishing was found to give the best final finish. The results of corrosion tests with 3% NaCl solution are briefly reported. Specimens that had been electrolytically polished before plating again gave the best results.—O. H. G.

Effect of Chromium Plating on the Endurance Limit of Steels Used in Aircraft. H. L. Logan. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 699–713). Chromium plating reduced the endurance limits of both normalized and hardened SAE X4130 and 6130 steels, the reduction being larger for hardened steels. For steel of a given hardness, the endurance limit decreased with increased plating-bath temperatures. Baking the steel after plating, at temperatures up to 350° C., reduced the endurance limit; baking at 440° C. increased it. The damaging effects of chromium-plating are attributed to stresses in the chromium or steel, which are increased by low-temperature baking, or are partly relieved by baking at 400–440° C.—T. E. D.

The Chromising Process. T. Gibson. (Sheet Metal Industries, 1951, vol. 28, June, pp. 569–571, 575; Metal Treatment and Drop Forging, 1951, vol. 18, May, pp. 201–204). The enrichment of the surface layers of steel articles with chromium by a gaseous process is now possible on a commercial scale. The process described was developed by the Metal-Gas Co., Ltd., a subsidiary of Colvilles, Ltd. The articles to be treated are packed with a solid granular mixture of ferro-chromium and a refractory ceramic, oxygen is expelled, and the retort then heated to 1050–1100° C. Gaseous anhydrous hydrogen chloride is passed into the retort and generates chromous chloride which in turn reacts with the iron in the article to produce chromium and gaseous ferrous chloride. A very uniform chromium-rich layer is formed on the steel surface, irrespective of any irregularities, discontinuities, and holes. The applications of the process and the effect of carbon and alloying elements are discussed.—P. M. C.

Barrel Deburring and Plating of Steel Stampings. E. A. Blount. (Products Finishing, 1951, vol. 15, May, pp. 28–32). The methods employed for deburring and bright nickel plating of stamped steel saucepan handles are described.—J. P.

Magnetic Roll Equipment for Tube Galvanizing Plant. (Iron and Coal Trades Review, 1951, vol. 162, June 22, p. 1434). **Tube Galvanizing Plant.** (Metal Industry, 1951, vol. 79, July 27, p. 65). A very brief description and illustrations are given of the Witton Kramer magnetic roll equipment installed at the Corby Works of Stewarts and Lloyds. The magnetic rolls are used to withdraw and convey galvanized tubes from hot spelter baths. The equipment will handle steel tubes from ¼ in. to 4 in. nominal bore and in lengths up to 21 ft. at speeds varying from 119 to 351 ft./min. The rolls are energized from a 220 V. supply.—P. M. C.

Galvanizing Pot Made of Pure Iron. H. Kalpers. (Metall, 1951, vol. 5, July, pp. 290–291). Commercially pure iron is recommended as a material for galvanizing pots on account of its resistance to attack by the zinc up to 490° C., its good thermal conductivity, and the ease with which it may be welded.—J. G. W.

A Review of Factors Influencing the Life of Galvanizing Pots. D. N. Fagg. (British Non-Ferrous Metals Research Association: Sheet Metal Industries, 1951, vol. 28, June, pp. 574–575). The B.N.F.M.R.A. have studied the factors affecting the lives of galvanizing pots, and for practical purposes it may be said that the life of such a pot depends in the main on the observance of the following conditions: (1) The temperature in all parts of the zinc bath shoud be controlled at below 480° C.; and (2) the silicon content of the steel used for the pot should not exceed 0·07%.—P. M. C.

Twenty Years of Research for the Galvanizing Industry. W. L. Hall and D. N. Fagg. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 14–29). Fundamental research carried out by the British Non-Ferrous Metals Research Association during the past 20 years is briefly described. In connection with the reaction between zinc and steel, effects of temperature, immersion time, withdrawal rate, various additions to the bath, and the nature of the basis steel have been studied. The most important conclusion is that for long pot life, the temperature should never rise above 480° C. Dross formation was investigated, and it was concluded that the chief danger is from iron salts carried over from the pickling tanks, indicating that there should be thorough washing. The drying operation following prefluxing could also be a serious source of iron salts if the temperature were not carefully controlled. The work done on resistance to corrosion by waters and the atmosphere is outlined.—T. E. D.

The Influence of Aluminium on the Alloying Action in Hot Dip Galvanizing. M. L. Hughes. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 31–43). Experi-

ments were performed employing Armco iron, commercial low-carbon, cold-reduced sheet of rimming quality, steel containing 0·10% C, and steel containing 0·22% C and 0·10% Si. Immersion times ranged from 5 sec. to 2 min. Temperatures varied from 430° C. to 490° C. and aluminium additions to the zinc bath from 0·05% to 3%. It was concluded that 0·10–0·18% Al is sufficient to produce coatings free from the usual alloy layers and 0·05% Al is sufficient to produce good bending properties. The presence of silicon in the steel enhances the effect of the aluminium. The formation of a very thin layer of $FeAl_3$, is responsible for the action of aluminium in preventing Zn–Fe alloy formation. The ' membrane ' and ' non-adherent alloy ' theories are disproved. The bending properties of the $FeAl_3$ are excellent.—T. E. D.

Some Thermal Considerations in the Heating of Galvanizing Baths. R. W. Bailey. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 51–62). The walls of galvanizing pots must be maintained at temperatures below 480° C. if excessive attack is to be avoided. Heat input should be mainly confined to the upper parts of the pot walls, and there should be no heating below the dross line. The heat requirements of a typical galvanizing bath are considered in detail. Heating systems and their relative merits are described, the importance of even heating and the use of thermostatic control being emphasized. The systems outlined are coke firing, external furnaces, external furnace with recirculation of gases, recuperative settings, radiant heating by gas and electricity, gas immersion heaters, and low-frequency induction. The relative costs of fuels are considered.—T. E. D.

Wet Galvanizing *versus* Dry Galvanizing. H. Bablik. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 76–81). The chemistry and practical considerations of galvanizing with molten flux on the surface of the bath, and with dry flux on the surface to be galvanized are discussed. The dry process must be used for aluminium alloy baths because of attack by the aluminium on the molten flux. Dross formation is lower in the dry process and lighter coatings can be obtained. The chief disadvantage of the dry process is the need for special, carefully controlled, drying ovens. Where articles varying in size and shape are to be galvanized the wet process is preferable because of its simplicity.—T. E. D.

Some Notes on the Relative Merits of Flux Galvanizing and Dry Galvanizing. T. Liban. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 82–84). The relative merits of flux galvanizing and dry galvanizing are: (1) Zinc losses in ash and flux skimmings average about 6·9% of the total zinc in flux galvanizing. In the dry process there is a loss of about 11%, even after the removal of metallic zinc from the ash. (2) Hard zinc formation is about the same in both processes. (3) Maintenance and service of the drying oven is an expensive item in the dry process. (4) The production rate is higher in flux galvanizing than in dry galvanizing.—T. E. D.

A Survey of the Formation of Zinc Ash, Dross and Flux Skimmings from Galvanizing Baths during 1949. R. W. Bailey. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 90–101). A survey was made by the Hot Dip Galvanizers' Association during 1949 on a typical cross-section of galvanizing baths. Questionnaries sent to the participating firms were divided into two sections, (*a*) covering the type of work being galvanized and quantitative data about the bath, and (*b*) concerning the technique employed and the physical dimensions and heating methods of the bath. The duration of the test period was three months, and 20 baths were kept under observation. The results are summarized in a table. Losses from ash formation and flux skimmings depend on the extent to which the bath surface is disturbed during operation, and the extent to which it is flux covered. The factors controlling dross formation are the washing away of iron salts after pickling and before dipping, the method and control of bath heating, and the throughput of work.—T. E. D.

Notes on New Methods of Drossing. H. Arnason. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 114–115). Methods developed by the J. Chr. Jensens Galvaniserings Etablissement, Copenhagen, are briefly mentioned.—T. E. D.

The Corrosion Resistance of Galvanized Coatings with Special Reference to Galvanized Window Frames. E. F. Pellowe. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 122–133). A typical process used for galvanizing steel window frames is described. Frames treated by the hot-dip galvanizing process are capable of withstanding rough handling in transit from factory to site as well as being very resistant to atmospheric corrosion, in unpainted and painted conditions. Tests demonstrating their corrosion resistance are described, and their behaviour in industrial service is summarized.—T. E. D.

The Outlook for General Galvanizing. R. L. Stubbs. (International Conference on Hot Dip Galvanizing, Copenhagen, July, 1950; Hot Dip Galvanizers' Association, Mar., 1951, pp. 140–148). The extents to which galvanizing is employed in the chief industrial countries are compared. There appears to be no immediate threat to galvanizing as a rust-preventing process; possible rivals include other metallic zinc coatings, aluminium coatings, tin coatings, paints, plastic coatings, chromium diffusion, and the use of non-rusting structural materials. A summary is made of possible improvements to the process, and the applications of galvanizing are surveyed.—T. E. D.

Hot-Dip Galvanizing of Powder Iron Compacts. H. Bablik, F. Götzl, and R. Kukaczka. (Sheet Metal Industries, 1951, vol. 28, Mar., pp. 277–281). A series of experiments is described, and many microphotographs are shown which indicate that hot-dip galvanizing of sintered iron-powder compacts can be satisfactorily carried out. In relation to corrosion, the results were equal to those expected from hot-dip galvanized rolled iron. Only very short pickling times are permissible, because of the rapid dissolution of compacted iron in mineral acids, and the galvanizing proper must be carried out according to the dry-galvanizing process, in order not to carry over superfluous water in the pores of the compacts which would tend to oxidize the zinc in the galvanizing bath.—P. M. C.

Continuous Electrogalvanizing. (Metal Industry, 1951, vol. 78, June 15, pp. 484–489). This article describes in detail the large continuous electrogalvanizing plant recently installed by Maclean and Co. (Metal Windows)Ltd., Hamilton. The plant, which is 300 ft. long, can treat 2500 large window frames per 48-hr. week and includes automatic phosphatizing and double-coat stoved painting. Full details are given of plant layout, solutions, and current consumption.—P. M. C.

Tin Plating. F. A. Lowenheim. (Metal Industry, 1951, vol. 78, May 25, pp. 423–425). The several methods of tin plating at present used by the American industry are discussed in a general manner. Reference is made to the rapidly expanding electrolytic process, for which four different types of electrolyte have already been developed, (the halogen bath, the cresol-sulphonate bath, and both sodium and potassium stannate baths). Installations for jobbing work, various other proprietary solutions, and immersion processes requiring no current supply are also dealt with.—P. M. C.

Properties and Uses of Tin. W. H. Dennis. (Mine and Quarry Engineering, 1951, vol. 17, May, pp. 149–155). Softness and plasticity of tin make it adaptable to all types of cold working where high tensile strengths are not required. The transformation from the white to grey form, known as tin pest, is peculiar to unalloyed tin or tin contaminated with zinc and aluminium, it does not occur in tin containing over 0·5% Sb, or 0·1% Bi, nor in alloys containing $\geqslant 5\%$ Pb. The proportions in which tin is used for different industrial applications are indicated. Sections are included on the application of tin coating, the tinning of steel, tinplate manufacture, tinning cast iron, the tinning of copper, tinned copper wire, and the electrodeposition of tin.—E. C. S.

The Development, Production and Manufacture of Electro-Tinplate. W. E. Hoare. (Sheet Metal Industries, 1951, vol. 28, Apr., pp. 309–321). A very comprehensive review is given of the continuous electro-tinning of steel strip. The different plating electrolytes in use at the present time are: The stannous phenolsulphonate bath, the halogen bath, the sodium stannate bath, and the potassium stannate bath. The compositions and working characteristics of these are presented, and full details and diagrams of plant layout are given for the Carnegie-Illinois phenolsulphonate line, the Weirton Steel Co. halogen line, and a typical sodium stannate line. There is a bibliography of 34 papers.—P. M. C.

Some Practical Notes on Tin–Zinc Alloy Plating for Ferrous Components. (Products Finishing, 1951, vol. 15, Jan., pp. 22–32). The process developed at the Tin Research Institute for the deposition of tin–zinc alloys from zinc-cyanide/sodium-stannate baths is described.—J. P.

The Electrodeposition of Iron. A. D. Squitero. (Products Finishing, 1951, vol. 15, Mar., pp. 22–42). Some simple, easily operated baths for the production of hard and of ductile iron deposits are described. Although electro-deposited iron cannot be applied universally as a substitute for other metals commonly deposited, the strong, dense, and relatively ductile metal can replace nickel and copper in many applications for electroforming, salvage, repair, wear resistance, and as an undercoating for other deposits. Examples of these uses are given.—J.P.

Which Coating for Gray Iron? C. O. Burgess. (Product Engineering, 1950, vol. 21, Oct., pp. 103–110). This article is concerned with the organic and chemical finishes that may be applied to grey-iron castings. These include organic paints, lacquers and enamels, synthetic resins, vitreous enamels, and phosphate coatings.—A. M. F.

Polyvinyl Chloride for Corrosion Protection. R. Nylander and V. Bergström. (Teknisk Tidskrift, 1950, vol. 80, Nov. 11, pp. 1035–1036). [In Swedish]. Properties and modes of application of 'PVC' as protective films are mentioned. A 0·4-mm. film gives efficient resistance against mechanical and chemical attack in most cases. The flame-spray method used for Polyethene coatings can unfortunately not be applied with 'PVC.'—B. S. E.

Practical Advantages Realized through Hot Spraying of Lacquer. J. A. Bede. (Products Finishing, 1951, vol. 15, May, pp. 38–46). The use of lacquer heated to about 160° F. for spraying gives the following advantages: (1) Increased production through uniform lacquer temperature, faster spraying times, fewer number of coats and freedom from blushing; (2) increased quality through greater depth and fullness of finish, better coverage of surface imperfections and freedom from coating defects; (3) reduced health hazards, *i.e.*, less spray fog and evaporated solvents; (4) reduced fire hazards; and (5) economies in labour, thinners (since the reduction of viscosity at high temperature reduces the proportion required), lacquer lost, and in air required. The type of lacquer heating equipment required is described.—J. P.

Methods of Testing Lacquer Coatings on Tinplate. W. E. Hoare. (Sheet Metal Industries, 1951, vol. 28, Mar., pp. 231–233, 244). The author first describes the British Standards test and the copper sulphate and thiocyanate tests, all of which are used to detect discontinuities in the lacquer coatings. Thickness, or weight tests, the Scotch-tape and the Porlin/Du-Pont impact adhesion tests, and taper bend tests are described. There are 20 references.—P. M. C.

Sherardised Castings. H. H. Symonds. (Metal Industry, 1951, vol. 78, May 18, pp. 407, 408). This article describes the results of fracture tests and micro-examination carried out on ten Sherardized malleable iron castings. An allegation that the Sherardizing treatment had introduced a state of brittleness into the material was refuted, the examination indicating that the trouble was caused by structural differences originating either in the grade of cast iron, or in the annealing treatment.—P. M. C.

Recent Metallizing Developments. T. A. Dickinson. (Steel Processing, 1951, vol. 37, Mar., pp. 122–125). Cathode sputtering and evaporation coating are two recently developed processes which have greatly expanded the field of metallizing techniques. In the former, the metal cathode of an electrical spark gap is disintegrated with high voltage electricity, the disintegrated particles being deposited on non-metallic surfaces. The latter method consists of vaporizing metallic materials in a small crucible or coil of tungsten through which is passed a heavy current, the metallic vapour again being deposited on neighbouring surfaces. Both techniques require to be performed in a vacuum chamber. Typical applications of these processes, and some general remarks about 'tumble' metallizing and the use of wire-consuming metallizing guns complete the article.—P. M. C.

Electric Furnaces for Vitreous Enamelling. (Sheet Metal Industries, 1951, vol. 28, June, pp. 576–578). A modern type of furnace, built by G.W.B. Electric Furnaces Ltd., is described and illustrated. The advantages of electric heating, as compared with other methods are discussed.—P. M. C.

Refractory Facing on Mild Steel. (Engineering, 1951, vol. 171, June 22, p. 763). A description is given of a new finish known as 'Stoneclad' developed by Matthews Refractories Ltd., It is designed to protect mild steel or cast iron from corrosion at high temperatures. The process consists in carrying, in a boro-silicate matrix, a suspension of insoluble refractories and bonding it to the metal surface by fusion at about 800° C. Experiments indicate that there may be many instances of high-grade heat-resisting steels being used where temperatures of 500° C. to 800° C. are encountered in which mild steel protected by the new process would give satisfactory performance.—M. D. J. B.

The Growing Role of Protective Coatings for Metals in High Temperature Service. W. N. Harrison. (Symposium on Corrosion of Materials at Elevated Temperatures, June 26, 1950, American Society for Testing Materials, Special Technical Publication No. 108, pp. 114–121). A brief survey of ceramic coatings is given and their use in the prevention of carburization is indicated. Accelerated corrosion tests with $PbBr_2$ vapour at 1350°, 1500°, and 1650° F. for successive periods of 1 hr. were made. Alloys tested were 347 Stainless, 19-9DL, Inconel, Vitallium, and S-816; ceramic coatings were effective in all cases. Photomicrographs of uncoated specimens show subsurface penetration, leaving a spongy surface layer. The correct choice of ceramic coating for a particular alloy is emphasized; it must have the correct coefficient of expansion.—T. E. D.

Surface Treatment of Iron and Metals with Paint and Similar Materials. S. Andersen. (Dansk Teknisk Tidskrift, 1950, vol. 74, Oct., pp. 342–367; Nov., pp. 389–392). [In Danish]. The principal pigments and binding media used for anti-corrosive paints are described and cleaning and application methods are given, the latter including electrostatic spraying and draining.—B. S. E.

POWDER METALLURGY

Mechanical Properties of Stainless Steel Powder. A. H. Grobe and G. A. Roberts. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 191, pp. 125–130; Journal of Metals, 1951, Feb.). This paper reports the mechanical properties of compacts of a pre-alloyed stainless-steel powder which is readily moulded at 30–50 tons/sq. in., can be sintered at low temperatures (2100–2300° F.), and yields compacts with both high strength and ductility. The powder is prepared by the liquid disintegration method direct from liquid metal, and has the following composition: 0·09% C, 2·42% Si, 0·63% Mn, 0·007% S, 0·019% P, 17·48% Cr, 8·02% Ni. The strength properties of a specially blended compact containing 62% of −325-mesh powder approach those of wrought material of the same composition.—G. F.

Design in Powder Metallurgy. H. W. Greenwood. (Metal Industry, 1951, vol. 79, July 6, pp. 3–5; July 13, pp. 31–33). This is a critical and detailed discussion of the basic principles of design of dies and tools for use in the pressing of powder metal compacts. The wide variety of complex shaped parts which can now be produced to very close limits of accuracy, is due largely to the advances made in die and tool design. The author discusses design with special reference to composition and grade of powder, shape and dimensions of compact, control of density, use of very slight taper to facilitate ejection, and reduction of die wear by employing carbide linings or hard chromium plating.—P. M. C.

The Mechanism of Sintering. P. Laurent and M. Eudier. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 271–275). The effect of time and temperature on the properties of compressed powders in a reducing atmosphere has been studied and various sintering mechanisms are discussed. After the reduction of superficial oxides the onset of sintering is shown by the increase in mechanical properties. Surface tension and internal stresses cause rapid agglomeration hindered momentarily by the reduction of internal oxides.

PROPERTIES AND TESTS

Determination of the Elastic Properties of Spring Materials. E. I. Zukovin. (Zavodskaya Laboratoriya: Hutnické Listy, 1951, vol. 6, Jan., pp. 41–42). [In Czech]. A simple testing device for determining the maximum elastic bending deflection of a specimen is described. The device is applicable for

applying loads of 0·05 to 10 kg. and measuring deflections between 0·1 and 100 mm. Basically, the deflection of a specimen supported at two points is measured as a function of the load, and the maximum elastic deformation is the point where load–deflection curve ceases to be a straight line. Examples of test results are given.—E. G.

Evaluation of Stress Distribution in the Symmetrical Neck of Flat Tensile Bars. J. Aronofsky. (Journal of Applied Mechanics, 1951, vol. 18, Mar., pp. 75–84). The local strains and the strain distribution in the necks of two flat tensile specimens were measured. A strain-hardening function for the material was obtained from the results of tension tests on round bars. This strain-hardening function and the measured strains were used to determine the stress distribution in the neck. Good agreement between the calculated and the measured fracture load was obtained.—J. P. S.

Effect of Heat-Treatment on Notched-Bar Impact Strength and Ageing of Mild Steel. E. Uhlir. (Betrieb und Fertigung, 1950, vol. 4, Aug., pp. 129–134). Notched-bar impact tests on an aluminium-killed 0·12% C steel showed that although heat-treatment had little effect on either the grain size or the impact strength, it greatly influenced the tendency to ageing. The drop in impact strength at room temperature after artificial ageing varied from zero for a steel heat-treated by quenching from 600° C. to 75% for a slowly cooled steel. Ageing is thus not so much a property of the steel as of its condition. Steels are delivered in a more or less stable condition, but after cold forming they must be stress-relieved at 600° C. rather than normalized.—H. R. M.

An Arbitration Bar Izod Impact Test for Cast Iron. J. Eash and A. Gagnebin. (American Society for Testing Materials, 1951, Preprint No. 15). An impact test for cast iron is described. It consists of breaking a section of unmachined bar in a modified Izod machine. The machine is described in detail, and data are given showing its usefulness over a range from 10 ft.lb. for high-phosphorus grey irons, to over 120 ft.lb. for austenitic cast irons.—E. T. L.

Notch-Toughness of Fully Hardened and Tempered Low-Alloy Steels. R. L. Rickett and J. M. Hodge. (American Society for Testing Materials, 1951, Preprint No. 31). Statistical analysis of data on Charpy impact strengths of steels with between 0·10 and 0·65% carbon shows that, in general, low-carbon steels are tougher than higher-carbon steels tempered at some higher temperature to produce the same hardness. The analysis confirms the tendency for notch-toughness to fall on tempering near 600° F. the magnitude of the fall depending on the temperature of test. Cooling quenched specimens to — 320° F. before tempering, does not eliminate the fall on tempering at 600° F.; evidently the fall is not caused by the presence of retained austenite.—E. T. L.

Effect of Variations in Notch Acuity on the Behaviour of Steel in the Charpy Notched-Bar Test. N. A. Kahn, E. A. Imbembo and F. Ginsberg. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 619–648). Data on the effects of small variations in the notch root radius of standard Charpy **V**- and keyhole-notch specimens, and on the transition temperature and energy absorption level of a number of steels are presented and discussed from the standpoint of establishing dimensional tolerances. The materials tested were Navy medium and high-tensile strength steels and SAE 1045 and 4620 steels. It is recommended that the root radius of the **V**-notch be specified as 0·010 + 0·0005, — 0·002 in., and the hole diameter of the keyhole-notch as 0·079 + 0·001, — 0·003 in. It is also suggested that the section thickness beneath the notch be specified as 0·315 ± 0·001 in. for the **V**-notch and 0·197 ± 0·002 in. for the keyhole-notch. In all other respects the specifications given in A.S.T.M. Method E23-47T are considered adequate. Data are included indicating that the effects of polishing the root of the standard 0·010-in. **V**-notch, and of machining this out in single and multiple cuts are negligible.—T. E. D.

Velocities of Steel Fragments after Perforation of Steel Plate. K. E. Spells. (Proceedings of the Physical Society, Section B, 1951, vol. 64, Mar. 1, pp. 212–218). Mild-steel fragments (right square prisms, 1·593 × 1·593 × 0·711 cm.) were projected normally with a velocity of 1469 m./sec. against mild-steel plates between 0·21 and 0·85 in. thick; usually impact was with the full square fragment face. Perforation occurred by removal of a plug rather larger than the fragment face, but tended to diminish with plate thickness. Fragment and plug were shattered by the impact, the pieces emerging along somewhat divergent paths. Velocities were measured with a Cooper chronograph, and in general were approximately the same for the principal pieces of fragment and plug. The residual velocity of the principal pieces may be predicted with reasonable accuracy for plate thicknesses up to about 0·5 cm. by assuming momentum to be conserved between the attacking fragment and a plug of equal area. For thicker plates this leads to too high values of the residual velocity, presumably because of the neglect of the motion communicated to the rest of the plate. Fragments of velocity 900 m./sec. suffered very little breakage against 0·21 cm. plates. The mechanism of penetration is discussed.—C. J. B. F.

The Propagation of Longitudinal Waves of Plastic Deformation in a Bar of Material Exhibiting a Strain-Rate Effect. L. E. Malvern. (Journal of Applied Mechanics, 1951, vol. 18, June, pp. 203–208). The theory of propagation of longitudinal waves of plastic deformation is extended to apply to materials in which the stress is a function of the instantaneous plastic strain and strain rate. Solutions are given for an idealized flow law and compared with solutions based upon earlier theories which neglect strain-rate effect. It is concluded that an assumed flow law, according to which the stress is a function of the instantaneous strain and strain rate, can account for discrepancies observed in the stress-time variation at the fixed end of impact specimens.—J. P. S.

The Constancy of Calibration of Elastic Calibrating Devices. W. C. Aber and F. M. Howell. (American Society for Testing Materials, 1951, Preprint No. 97). Two Amsler boxes have been calibrated by the National Bureau of Standards nine times since 1933, showing an average decrease of calibration of 0·03% each year. Two loop dynamometers which give deflections on dial indicators have remained substantially constant since 1944.—E. T. L.

A Review of Some Electronic Instruments for Use in Industry. S. F. Smith. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1951, vol. 28, Mar., pp. 247–255). The author first describes in detail the use of electrical resistance strain gauges, and the many types of measuring instrument with which the resistance changes may be measured. The inductance-type electrical extensometer is also described, and the relative merits and different applications of this and the resistance gauge are discussed. Methods of dynamic testing by using vibration pickups are outlined, and the use of stroboscopic equipment for viewing cyclic movements is described.—P. M. C.

Wire Strain Gauges for Elevated Temperature Service. D. J. DeMichele. (Product Engineering, 1950, vol. 21, Oct., pp. 115–117). The problems involved concerning the selection of gauge wire, bonding cement, and leads between the gauge and recording instruments for use in applications between 700° and 1500° F. are discussed. A high-temperature gauge developed by the General Electric Co. consists of 85% platinum 15% iridium wire fabricated on mica in a closely spaced flat grid. The gauge is bonded to the specimen with Sauereisen No. 31 cement over a coating of insulating cement. The design of slip rings is also mentioned.—A. M. F.

Hydrogen Theory for Brittle Ship-Plate. C. A. Zapffe. (Metal Progress, 1951, vol. 59, June, pp. 802–808). In the first world war attention was focused on an internal cracking defect termed 'flake,' since found to be due to hydrogen solution during basic steelmaking. The cure was drying the lime used for making slag, and reduction of internal stresses by slow cooling. The author suggests the cause of the more recent problem of brittle fracture of welded ship plates is also hydrogen absorption, but on a smaller scale. A possible cure lies in the use of oxygen lances during steelmaking to reduce the hydrogen content.—E. T. L.

The Nature and Causes of Fractures of Some Types of Steel. V. Koželev. (Hutnické Listy, 1951, vol. 6, Mar., pp. 106–110; Apr., pp. 165–179). [In Czech]. The factors which determine the appearance of fractures are investigated and some fundamentals are defined. Descriptions of some characteristic fractures are given, their nature is explained and the conditions causing a given type of fracture are also described in some cases. Pseudomorphism and intercrystalline fractures are dealt with. The author discusses the fractures of sorbitic and pearlitic steels. He believes that pearlitic fracture is influenced by the size and number of defective spots and suggests a new method for obtaining relief fractures of specimens broken in tension; specimens

produced according to this method permit better study of the process of development of fractures. There are 69 figures, most of which are microphotographs of steel fractures.—E. G.

Zinc Embrittlement. (Aircraft Production, 1951, vol. 13, July, p. 201). Zinc alloy punch and die were found by Airspeed Ltd. to be responsible for surface impregnation with zinc of drop-hammer pressings in D.T.D. 493 heat-resisting steel. After heat-treatment, cracks appeared due to weakening of grain boundaries, but pickling in a nitric and hydrofluoric acid bath before heating eliminated this trouble. It is recommended that other tool materials should be employed when a long run is expected.—T. E. D.

Failure of Heat-Treated Rails. M. Marx. (Ossature Métallique, 1950, vol. 15, July–Aug., pp. 355–357). Some rails of which the upper part had been quenched were found to be scaling in service. Although the explanation is not yet known, research carried out by the Société Minière et Métallurgique de Rodange revealed that in certain circumstances a very ductile pseudo-martensitic layer is formed between two sorbitic layers during quenching. It was detectable only by the Rockwell C hardness test. By applying the knowledge so gained the above Company is now able to make rails which do not scale.—N. MCE.

Production Problems—III: Fracture Characteristics of Malleable Iron Castings. (Iron and Steel, 1951, vol. 24, Apr., pp. 122–123). This article describes an investigation of the pronounced differences in fracture characteristics of various malleable iron castings. It is shown that the differences are largely due to variations in structure after malleablizing, a high combined carbon content being conducive to the unsatisfactory crystalline fracture.—G. F.

Production Problems—IV: Prematurely Broken Crankshaft. (Iron and Steel, 1951, vol. 24, May, pp. 179–180). A description is given of an examination of a steel crankshaft which had prematurely failed. Micro-examination showed the steel to be of the free-cutting type, and it is suggested that, although the properties of the steel were more or less adequate, a non-free-cutting type should be used. Failure was due to a broken grub-screw or locating-pin working into the shaft, there being no indication of fatigue failure.—G. F.

Testing Machines for the Determination of the Fatigue Strength of Materials and Components. K. Gutfreund. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1951, vol. 6, Feb. 15, pp. 34–38). The principles and construction of the range of tension-compression and alternating torsion fatigue testing machines made by Carl Schenck G.m.b.H. of Darmstadt are described.—H. R. M.

Planning and Interpretation of Fatigue Tests. A. M. Freudenthal. (American Society for Testing Materials, 1951, Preprint No. 16). Considerations of the wide scatter of the results of fatigue tests show the necessity for an extension of the usual stress-cycles diagrams to a three-dimensional representation, which includes a term for the probability of a particular result. The distribution of the fatigue life N, of specimens tested at stress S, is approximately logarithmic-normal. To find the mean value of the fatigue life at any stress, at least six specimens must be tested at that level. This theory is checked by rotating-beam and reversed-torsion fatigue tests on steel, aluminium, and copper.—E. T. L.

Statistical Aspects of Fatigue Strength. W. Weibull. (Teknisk Tidskrift, 1950, vol. 80, Nov. 18, pp. 1059–1064). [In Swedish]. The author attempts a general correlation between stress and the number of cycles required for fracturing or a certain probability for fracture. The P–S–N diagram expresses the life N of a machine element as a function of the stress S and the fracture probability P. By extrapolation of $N \to \infty$, the ranges of the S–N field, which have received little experimental investigation, become accessible for mathematical treatment.—B. S. E.

Shot Peening: Effect on the Fatigue Properties of 18:8 Chromium–Nickel Steel. W. E. Bardgett and F. Gartside. (Iron and Steel, 1951, vol. 24, June, pp. 195–197). The authors describe an investigation into the effect of shot peening on the fatigue properties of 18/8 stainless steel, using rotating cantilever machines. The results show that, using 40-grade shot at 40 lb. pressure for 15 sec., the limiting fatigue stress is 11% for 0·3-in. dia. specimens and 46% for 0·14-in. dia. specimens, the optimum increase in fatigue strength in the latter case being obtained with exposures of 15–30 sec. The reduced benefit with greater exposures is not attributable to surface cracking. The surface appearance is roughest after 15 sec., and the structure near the surface shows little evidence of dislocation with exposures up to 60 sec.—G. F.

The Effect of Surface Roughness on the Alternating Bending Strength of Unhardened and Tempered Steel. H. Glaubitz. (Department of Scientific and Industrial Research Sponsored Research (Germany), Report No. 1). Round bars, either turned (rough or finished), ground, or polished, of St 70.11 and VCMo 140 were tested in a Foeppl-Heydekampf alternating bending machine; a correlation with surface roughness was obtained.—T. E. D.

Effect of Residual Stress on the Fatigue Strength of Notched Specimens. D. Rosenthal and G. Sines. (American Society for Testing Materials, 1951, Preprint No. 17). An attempt is made to predict the effect of residual stress on the fatigue life, allowing for cold-working and heat-treatment, and the partial relief of residual stress occurring during fatigue testing. The prediction was based on X-ray data with a modified Goodman diagram of the unnotched specimen, and gave quantitative agreement with the results on two aluminium alloys. It was found that, in the absence of any other effect, residual stress alone, induced at the base of the notch in a fatigue specimen, can have a beneficial as well as a detrimental effect on the fatigue strength, depending on the sign which in turn depends on the extent of the change in the residual stress that the first few cycles cause. Whether the residual stress is important appears to depend on whether the ratio of yield point to fatigue limit exceeds the ratio of the stress concentration factor to the fatigue strength reduction factor.—E. T. L.

The Influence of Surface Roughness on the Fatigue Life and Scatter of Test Results of Two Steels. P. G. Fluck. (American Society for Testing Materials, 1951, Preprint No. 20). This paper presents the results of tests on fatigue specimens of two different steels, prepared by six different methods of surface finishing. These show as much as a tenfold increase of life due to polishing of turned specimens. Groups of twelve specimens were tested to provide data on the scatter of results, and they showed that gentle grinding gave high and uniform results, even though large longitudinal scratches remained on the specimens. Circumferential scratches on the other hand were found to be deleterious.—E. T. L.

Damping, Fatigue, and Dynamic Stress-Strain Properties of Mild Steel. J. Lazan and T. Wu. (American Society for Testing Materials, 1951, Preprint No. 22). This paper gives the results of tests, using a recently developed rotating-beam testing equipment, to find the damping energy, dynamic modulus of elasticity, and fatigue properties of steel. The data relate to the variables of stress magnitude and history, frequency, and rest, and are analysed with reference to the concept of 'cyclic stress sensitivity limit,' below which damping is independent of stress history, rest, or frequency. A new type of representation is introduced to account for the damping during fatigue tests.—E. T. L.

Fatigue Strength of Ball Bearing Races and Heat-Treated 52100 Steel Specimens. H. Styri. (American Society for Testing Materials, 1951, Preprint No. 23). It is shown that a wide scatter of results is given by fatigue testing, even with slag inclusions reduced to a minimum by vacuum-melting. It is concluded that the starting point of failure is not at a foreign inclusion, but at points of local weaknesss in a region under the path of rolling contact, in the case of ball-bearings, where shear stresses are high. The median of the life of ball bearings varies with the inverse cube of the bearing load, *i.e.*, inversely to about the tenth power of the pressure at the point of contact.—E. T. L.

Laboratory Evaluation of Materials for Marine Propulsion Gears. M. R. Gross. (American Society for Testing Materials, 1951, Preprint No. 38). This paper gives results on the 'root fatigue strength' of materials for marine gears, measured by a new 'simulated gear tooth fatigue test,' and also results of pitting resistance tests. For through-hardened steels the pitting resistance increases linearly with hardness, being particularly high after carburizing or nitriding treatments of the specimens.—E. T. L.

Prestressing Processes and Fracture Barriers. (Product Engineering, 1951, vol. 22, Mar., pp. 102–124). The results of a number of investigations into the effects of prestressing on fatigue life are discussed and it is pointed out that a number of processes which involve leaving material in a compressively stressed state unwittingly form fatigue barriers. Carburizing, nitriding, flame hardening, and welding are some

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of these processes, and detailed examples of each type are quoted. It is further pointed out how the effects of peening stresses can be lost.—A. M. F.

High Stress Fatigue of Alloy Steels. T. T. Oberg and W. J. Trapp. (Product Engineering, 1951, vol. 22, Jan., pp. 159–163). The results of fatigue tests for axial loading and reversed bending of three aircraft steels are given. These steels are SAE 2330, 4340, and 8630; their rate of loading varied between 90 and 3450 cycles/min. and applied loads were chosen to fail most specimens between 5000 and 100 million cycles.—A. M. F.

Vibration and Fatigue Life of Steel Strand. J. C. Little, D. G. MacMillan, and J. V. Majercak. (Transactions of the American Institute of Electrical Engineers, 1950, vol. 69, pp. 1473–1579). An investigation is described of the fatigue life of 7-wire strands of steel in various conditions as encountered when used to protect electric cables. Data obtained with a rotating-strut-type fatigue testing machine on specimens of high-strength and extra-high-strength galvanized wire, and stainless-steel wire at − 55°, + 77°, and + 200° F. are presented. Some modifications to specifications of the National Electrical Safety Code are suggested.—R. A. R.

The Fatigue Strength of Steel through the Range from ½ to 30,000 Cycles of Stress. M. H. Weisman and M. H. Kaplan. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 649–665). Data from the relatively few reports in the literature which include figures for lifetimes of less than 50,000 cycles, are compiled and replotted in terms of life against stress in per cent of tensile strength. Tests were conducted to obtain short-life fatigue data for SAE 4340 steel, heat-treated to 215,000 lb./sq. in. tensile strength. Fatigue strength curves based on the information compiled are presented for both smooth and notched specimens and for unidirectional as well as for reversed loading. The axial load stress/cycles (S/N) curve for the stress range zero to maximum stress is complete from half cycle to the endurance limit. The S/N curves for reversed bending, reversed axial loading, and rotating-beam fatigue tests are complete from about 1500 cycles to the endurance limit.—T. E. D.

Fatigue Notch-Sensitivities of Some Aircraft Materials. H. J. Grover. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 717–734). This paper reviews data on the fatigue notch-sensitivities of a number of materials used in aircraft. The materials considered are three SAE steels (4130, 4140, and 4340), two aluminium alloys (24 S-T and 75 S-T), and 18/8 stainless steel. The data are arranged in groups: (1) Rotating-beam test, (2) repeated-bending test, (3) repeated-torsion test, and (4) axial-loading test. The results are considered inadequate in extent and nature for any general conclusions to be reached.—T. E. D.

Modern Hardening Methods. E. Knuth-Winterfeldt. (Dansk Teknisk Tidskrift, 1950, vol. 74, Oct., pp. 337–341; Nov., pp. 385–420). [In Danish]. The first part of this descriptive treatise deals with oven types and temperature and hardness control, whilst the second part is an exposition of common heat-treatments.—B. S. E.

Measuring the Hardenability of Steels. E. G. Bildsöe. (Dansk Teknisk Tidskrift, 1950, vol. 74, Sept., pp. 294–296). [In Danish]. The Jominy hardenability test is described, with details of apparatus and procedure.—B. S. E.

Hardness Testing. H. Schulz. (Microtecnic, 1951, vol. 5, Jan.–Feb., pp. 6–9). Consideration is given to the deficiencies of practical hardness testing. The results from grinding and scratch hardness tests are not identical for basic substances nor even for materials which do not possess a crystalline structure. Under various test methods, the difficulties are caused not only by the material used for altering the surface of the specimen but by the shape of the indenter. A description is given of the microhardness tester by Hauser S. A., Bienne, Switzerland, which incorporates a pyramid, making the testing of small specimens possible. A device is also included which makes it easy to bring the indentation within the visual of field the measuring microscope.—H. D. W.

Three-Faceted Diamond Pyramid for Microhardness Testing. E. S. Berkovich. (Zavodskaya Laboratoriya: Industrial Diamond Review, 1951, vol. 11, June, pp. 129–132). Diamond indenters used in microhardness tests are usually square-based pyramids. As it is difficult to produce a four-sided pyramid with all four facets meeting in a common point, the usefulness of a three-sided pyramid is examined. The results of tests comparing the two types of pyramid indenters are given.—T. E. D.

Microhardness Tester for Vickers and Knoop Hardness Tests. K. Frank. (Zeitschrift des Vereines Deutscher Ingenieure, 1951, vol. 93, June 11, p. 475). A new microhardness tester is briefly described and illustrated. It has two loading ranges, 1–50 g. and 100–500 g., and an adjustable indentation speed. The indenter is of the Knoop type, producing a rhombic indentation, the ratio of the diagonals being about seven to one and the depth of penetration being one-thirtieth of the longer diagonal. The instrument is particularly suitable for the testing of thin and small specimens, metal inclusions, jewels, semi-precious stones, and ceramics.—J. G. W.

Acceptance Sampling of Steels Submitted to Hardenability Specification. A. Palazzi. (Metallurgia Italiana, 1951, vol. 43, May, pp. 185–189). Based on practical and theoretical considerations, a plan is put forward for acceptance sampling of steels submitted to hardenability specifications. A detailed review is given of present sampling methods for determining the behaviour and characteristics of hardenable steels. Considerable technical information is given together with a bibliography.—M. D. J. B.

Study of Natural Ageing and Application of Tests for Determining the Weldability of Steel. F. Pobořil and F. Šicha. (Hutnické Listy, 1951, vol. 6, Apr., pp. 158–165). [In Czech]. The authors report on results of natural ageing tests of long duration, carried out to determine whether their effect is the same as that of artificial ageing. The tests lasted from 2 to 10,000 hr. after which impact tests and measurements of the macro- and micro-hardness were carried out. Steel with a strong tendency to embrittlement developed full brittleness in 24 hr. after the 'critical heat-treatment' (quenching in water from 710° C.) and remained for 10,000 hr. without any sign of improvement. With killed steel, full brittleness occurred in 500 hr. after the critical heat-treatment and there was no improvement after 10,000 hr. To determine whether increase of impact strength values between 5000 and 10,000 hr. indicates an improvement in forging properties, specimens were given 15,000- and 20,000-hr. ageing tests. These long tests proved the existence of precipitation-hardening for low-carbon steels quenched in water from temperatures directly below the Ac_1 point. Simultaneous tests of natural ageing following cold deformation proved that there is a difference between this type of ageing, which results in only a slight increase of hardness, and ageing after quenching in cold water from a temperature directly below the Ac_1 point. Statistical data from weldability tests obtained during current quality control on 125 low-carbon steel melts showed that ageing after 'critical' heat-treatment and ageing after cold deformation give quite different results for a large number of the tested steels. The assumption that a steel has an equal tendency to embrittlement as a result of thermal cycles during welding and as a result of cold deformation is not always correct. In most cases, the steels unsuitable for welding were unkilled.—E. G.

Ageing of Steel and Its Relationship to Oxygen and Nitrogen. U. Engelbert. (Australian Institute of Metals: Australasian Engineer, 1951, Apr. 7, pp. 73–79). The phenomenon of quench and strain ageing in mild steel, as a function of the solubilities of oxygen and nitrogen in liquid iron, is discussed in some detail. Mention is also made of various steelmaking methods (Mannesmann M.A. and Gutehoffnungshütte H.P.N. processes), and of aluminium treatments, which are designed to avoid any susceptibility to ageing. There are 21 references.

P. M. C.

The Nature of Ferromagnetism. B. Oom. (Teknisk Tidskrift, 1950, vol. 80, Nov. 4, pp. 1001–1004). [In Swedish]. The author gives a comprehensive outline of the conditions for occurrence of ferromagnetism and its correlation with the atomic structure.—B. S. E.

Ferromagnetism of the Alloy $FeBe_2$. A. J-P. Meyer and P. Taglang. (Comptes Rendus, 1951, vol. 232, Apr. 23, pp. 1545–1546). This stoichiometric alloy has a Curie point of 643° C. and a temperature of magnetic isotropy at 468° C. Its saturation moment of $M_{mol} = 2{\cdot}24\mu_B$ (T = 0° K.) appears to be due only to the iron atom which retains its moment in spite of the large excess of electrons supplied by beryllium. This supports the hypothesis of orbital contraction in this type of alloy.—A. G.

Origin of Intermittent Activation in Ferromagnetics. R. Forrer. (Comptes Rendus, 1951, vol. 232, May 7, pp.

1746–1748). The formula, intermittent activation a = constant $\times$ $n''.n'$ is postulated where n'' is the number of electron pairs and n' the number of single electrons. For normal ferromagnetics this becomes a = constant.$(n''-2)$. n'. Ferromagnetism is found to be confined within the boundary given by these two equations showing that intermittent activation is primarily an internal effect dependent on atomic number.—A. G.

The Development of a Flaw Detector for Tubes. R. D. Kodis. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 1196–1206). The alternating current bridge method of magnetic flaw detection was investigated and found to be unsuitable for production inspection of tubes for cracks. The induction method of detection was then studied. A suitable detector was designed, using the theory of magnetic recording heads, which, by the use of a low permeability gap in the magnetic circuit, concentrates the sensitivity of the detector at the gap. This was used in conjunction with a Helix Facsimile Recorder, which prints the cracks directly in picture form on electro-sensitive paper. This method has speed, reliability, definition, and sensitivity for inspecting gun tubes, and could be used as a production inspection method.—T. E. D.

New Instruments for Magnetic Non-Destructive Testing. W. Jellinghaus. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 111–115). New instruments for the detection of faults in materials and for separating one material from another are reviewed. The Ferrotest for solid bars employs the usual alternating current and the potential generated in a movable secondary coil around the test piece is opposed by that generated in a similar way on a control specimen. Any fault or variation in the bar being tested gives rise to a potential in the secondary coil which can be used to deflect a cathode-ray beam, and thus indicate the fault. By choosing suitable phase angles, the sensitivity of the instrument for various types of defect can be increased. The other instruments use an exploring head, which in the crack detector and crack 'viewer' takes the form of a coreless transformer; the specimen acts as the core. The potential induced in the secondary is fed to an oscilloscope and any defect in the specimen is indicated as a deflection of the beam as the head is moved over the surface of the specimen. In the sorting instrument, the probe head is used to determine the residual field in the neighbourhood of small articles after a magnetizing field has been switched off. It is claimed that this residual field varies with different materials or different heat-treatments and can be used successfully to sort out apparently identical articles.—J. P.

Non-Destructive Testing in the Steelworks. J. F. Hinsley. (Engineering Inspection, 1951, vol. 15, Spring Issue, pp. 2–7, 23). A general review of non-destructive testing is given, and certain methods which have been brought to the front in the last decade are described in detail. These comprise ultrasonic, magnetic, and radiographic methods. The equipment, its manipulation, and the fields of use of each method are outlined.—P. M. C.

The Design of Resonant Quartz-Crystal Ultrasonic Transducers for Research Purposes. G. W. Swanson, jun., and W. T. Thomson. (Journal of Applied Mechanics, 1950, vol. 17, Dec., pp. 427–430). The author points out that piezoelectric crystals excited by a source of alternating voltage are commonly used as a method of producing ultrasonic mechanical vibrations. The paper is intended to co-ordinate the several approaches to the design problem and to present a practical method for designing quartz-crystal transducers for ultrasonic frequencies.—J. P. S.

New Possibilities for Short Wavelength X-Ray Stress Measurement. H. Möller. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 137–142). The diffuse self-radiation of steel, subjected to molybdenum radiation, can be suppressed by a 0·2-mm. aluminium foil without inconveniently lengthening exposure times. Back-reflection photographs can show up the (732) and (651) interferences and, with less intensity, the (800) interferences. The back-reflection lines remain sharp even with samples cold-reduced by 46%. A special camera has been built, and is described, for stress measurements. The value of this technique for practical applications is discussed. It need not be restricted to molybdenum radiation; indeed, still shorter wavelengths should reveal lines of even higher indices. The method should be of particular advantage in testing material with cold-worked surfaces. On the research side, it is necessary to extend our knowledge of the effects of elastic anisotropy, lattice distortion, and particle size. Shortwave radiation should be of great use in this connection.—J. P.

Alignment Chart for the Bragg's Equation. E. Tavora. (Anais da Academia Brasileira de Ciencia, 1950, vol. 22, No. 4, pp. 441–443). [In English]. The rapid determination of d/n values required when identifying substances by the Debye-Scherrer method is of great importance and, in consequence, the use of tables and nomograms is becoming more general. In this paper a nomogram is presented which affords the minimum accuracy required by the systematic interpretation of the X-ray films from conventional powder cameras.—R. A. R.

Evaluation of Soundness in Cast Iron. (Institute of British Foundrymen, Report and Recommendations of Sub-Committee T.S.20 of the Technical Council, 1951). After a detailed investigation of various non-destructive methods of detecting and measuring the extent of unsoundness in iron castings, the following conclusions were reached: (1) For the precise location of any form of unsoundness producing a local variation in opacity to gamma or X-rays, radiography is recommended. Quantitative evaluation can be achieved by comparison with carefully prepared comparator charts. (2) Ultrasonic methods can be applied to thick sections beyond the range of X-rays. As with radiography, uniformly dispersed fine porosity is not detected. In addition, free graphite interferes with the examination of grey cast iron. (3) Electrical, magnetic, and relative density methods are of very limited value. (4) Other methods, such as indentation hardness, pressure tests, and vitreous enamelling were examined and found to be unsuitable for general use. Methods (1) and (2) are treated in detail.—T. E. D.

Fundamental Concepts, Experimental Data, and Recent Work on Creep. E. Morlet. (Revue Générale de Mécanique, 1951, vol. 35, Jan., pp. 9–16; Mar., pp. 86–93). Continuation of a series of articles (*see* Journ. I. and S.I., 1951, vol. 169, Sept., p. 86). The principles of creep-testing machines are explained and details of the Trayvou, Rateau, and TR (Chevenard) systems are given. The following methods of defining creep rate are examined: Bureau Veritas; Zurich Institute for Testing Materials; National Physical Laboratory; W. H. Hatfield; Kaiser-Wilhelm-Institut für Eisenforschung, German Standard (D.I.N.); U.S. Bureau of Standards; and D.V.M. (German). Methods of determining creep by extrapolation are discussed. Long-time creep tests are also described. The properties of A.T.V. (35/12 Ni–Cr steel for steam-turbine blades) from the Imphy Steelworks, developed by Chevenard and of high cobalt austenitic steels are discussed together with the influence of mechanical working, heat-treatment, and grain size on these properties.—R. A. R.

The Creep Test Envisaged As a Process of Physicothermal Analysis. P. Chevenard and X. Waché. (Comptes Rendus, 1951, vol. 232, June 11, pp. 2161–2164). If elongation-time curves at constant temperature and load have an accuracy sufficient to enable graphical determination of rates, the method can detect and study changes occurring in heat-resisting alloys during their use in thermal machines.—A. G.

Interpretation of Tension Creep–Time Relations. J. Marin and L. W. Hu. (Bulletin of the American Society for Testing Materials, 1951, Jan., pp. 57–59). A creep–stress relation for creep of metals at elevated temperatures is proposed. It is simple to use, takes into account the primary and secondary stages of creep, and fits test data on the four steels and two cast irons considered.—T. E. D.

An Evaluation of the Effective Gage-Length Equivalent of the Fillet and Shoulder of the Gage-Length Portion of a Tension Test Bar under Creep and Stress-Rupture Conditions. H. V. Kinsey. (Bulletin of the American Society for Testing Materials, 1951, Jan., pp. 60–62). The errors introduced into creep measurements by creep occurring in the shoulders and fillets of test specimens are examined, three high-temperature alloys, S-816, Inconel X, and 73J, being used as examples. It is not possible to arrive at a common correction factor for the equivalent gauge length, if this is to be known to within $\pm$ 1%, unless a specimen with an 8-in. gauge length is employed.—T. E. D.

Some Observations Concerning the Fatigue Strength of Welded 18/8 Steel at High Temperature. I. Weibull and P. Davidson. (Jernkontorets Annaler, 1950, vol. 134, No. 12, pp. 559–571). [In Swedish]. A carbon content above

0·02–0·03% necessitates the use of a stabilizer to prevent carbide formation at the grain boundaries in the welded steel joint. Niobium and titanium are almost equivalent as stabilizers, but niobium should be given preference since less is burned out during welding.—B. S. E.

Effect of Various Treatments on the Fatigue Strength of Notched S-816 and Timken 16–25–6 Alloys at Elevated Temperatures. W. E. Jones, jun., and G. B. Wilkes, jun. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 744–762). The fatigue strengths of notched specimens of a cobalt-base alloy, S-816, and a highly alloyed iron-base alloy, Timken 16Cr–25Ni–6Mo, have been determined from room temperature to 1200° F. The results indicate that the behaviour of a notch depends on how it was made, *e.g.*, ground notches tend to contain tensile stresses to a degree depending on the severity of grinding. The elevated temperature tests supply the actual fatigue strength, and when compared with the room-temperature tests, indicate the state of stress at room temperature. Various corrective treatments to improve the notched strength were tried. Shot-peening, coining, rolling, etc., set up compressive stresses in the surface, increasing the strength as well as helping to correct any tensile stresses that have been produced in making the notch. If such treatment is impracticable, a stress-relief anneal or complete heat-treatment will remove tensile stresses present. In service at elevated temperatures, the improvement obtained by cold-working treatments becomes less as the temperature is increased.—T. E. D.

Strength of Pipes under Internal Pressure at Very High Temperatures. E. Siebel and S. Schwaigerer. (Brennstoff, Wärme, Kraft, 1951, vol. 3, May, pp. 141–143). Permanent creep will occur in tubes working at temperatures above 525° C., even when high-alloy steels are used. The authors show that, for small ratios of diameters, dimensions can be chosen so that mean deformation does not exceed 1% during a working period. Formulæ valid for fully plastic conditions are applied. With higher ratios of diameters, *i.e.*, with greater wall thickness, deformation variation across the tube wall is taken into account, maximum change on the inner surface again being limited to 1%. The method of calculation applies also to tubes with uneven temperature distribution.—E. C.

Microstructural Instability of Steels for Elevated Temperature Service. G. V. Smith, W. B. Seens, H. S. Link, and P. R. Malenock. (American Society for Testing Materials, 1951, Preprint No. 28). A series of charts gives the results of examinations of the changes of microstructure, hardness at room temperature and notch-impact strength at different temperatures, after exposure of 18 steels for 14 months at either 900, 1050, or 1200° F. In the low-alloy steels carbide spheroidized, and a fine precipitate formed, without noticeable graphitization. In the high-chromium grades carbide again spheroidized, and sigma phase formed. The changes in structure of both the ferritic and the austenitic steels led to impairment of notch-impact strength in two-thirds of the cases, and improvement in about one-tenth.—E. T. L.

Prediction of Relaxation of Metals from Creep Data. I. Roberts. (American Society for Testing Materials, 1951, Preprint No. 37). In the first part of this paper the author considers the various assumptions that might be made in deriving an empirical equation for predicting a metal's creep rate in tension. Then he applies to these the results of some tests on copper, carbon steel, and the alloy S-816, to show the validity of assuming strain-hardening. It also appears that time-hardening and creep-recovery are negligible at the temperatures in question, which in the case of steel was 1500° F.—E. T. L.

Effect of Temperature on the Mechanical Properties, Characteristics, and Processing of Austenitic Stainless Steels. V. N. Krivobok and A. M. Talbot. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 895–928). The effects of processing, (rolling, etc.) commercial austenitic stainless steels such as American Iron and Steel Institute, 301, 302, 304, 310, and 347, at temperatures from 0° to — 320° F. were investigated, showing that the mechanical properties and other characteristics of the steels were improved by such treatment. The mechanical properties at sub-zero and at elevated temperatures were determined for steels rolled at room temperature and at sub-zero temperatures. The effects of sub-zero and of elevated temperatures on the properties at room temperature were also studied. The effects noted were discussed in connection with the forming process.—T. E. D.

The Properties of Molybdenum and Tungsten at High Temperatures. J. W. Tomlinson and J. O'M. Bockris. (British Iron and Steel Research Association, 1950, Publication CP/2/4). Molybdenum and tungsten are finding increasing applications in work within the temperature range 1000–2500° C. Literature concerned with the thermal, electrical, mechanical, and chemical properties of the two metals is collected and critically reviewed from the physiochemical viewpoint. There are 138 references.—T. E. D.

The Effect of Environment on the Stress-Rupture Properties of Metals at Elevated Temperatures. O. C. Shepard and W. Schalliol. (Symposium on Corrosion of Materials at Elevated Temperatures, June 26, 1950; American Society for Testing Materials, Special Technical Publication No. 108, pp. 34–38). Stress-rupture tests in controlled atmospheres on low-carbon steels, carbon–molybdenum steel, and Hastelloy 'C' showed that small changes in the composition of the environment produce large differences in the amount of intergranular cracking and time of failure. The need for making the tests in environments similar to their service conditions is emphasized.—T. E. D.

Gases in Cast Iron. R. V. Riley. (Iron and Coal Trades Review, 1951, vol. 162, May 11, pp. 1083–1090). The author briefly reviews past work on the subject of gases in cast iron and discusses the necessity for further investigation. The vacuum-fusion method of gas analysis is described, followed by the results and conclusions of experiments in the author's laboratories. Segregation of gases in cast iron is then discussed, and the effects of moulding methods, furnace melting conditions, and ageing on the gas content of iron are considered.—G. F.

The Influence of Cold Working on the Internal Friction of Iron and Steel with or without Hydrogen. P. Bastien and P. Azou. (Comptes Rendus, 1951, vol. 231, May 16, pp. 1845–1848). The effect of hydrogen segregation during gradual deformation is studied by measuring internal friction by (*a*) Columb's pendulum, and (*b*) Cabaret elasticimeter. Using method (*a*) the logarithimic decrement was found to increase with initial amplitude when hydrogen was present. For the feeble stresses and very high frequencies of method (*b*) the internal friction increases rapidly beyond 10% working. The results show the necessity of plastic deformation to provoke the action of hydrogen.—A. G.

Effect of Alloying Elements on True-Stress True-Strain Flow Curves of Pearlitic Steel. R. Raring, J. A. Rinebolt, and W. J. Harris, jun. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, May, pp. 395–400; Journal of Metals, 1941, May). The authors describe an investigation of the effects of additions of alloying elements on the true-stress true-strain characteristics of 0·3% C, 1·0% Mn, 0·3% Si pearlitic steel. Many alloying elements were considered (C, Mn, Si, P, Ni, Cu, V, Mo, Cr, Al, B, S, and Ti). It is shown that all the elements increase the height of the true-stress true-strain flow curve, with the exception of aluminium, boron, sulphur, molybdenum, and titanium, the effects of which were too small to permit reliable evaluation. As the height of the flow-curve increases, the strain-hardening exponent decreases and the strain-hardening rate increases, the latter increase varying with composition. The energy to fracture is increased by manganese, nickel, and chromium, and is decreased by carbon, silicon, phosphorus, molybdenum, copper, and vanadium. The ratio of strain-hardening rate to the intercept at zero stress is variable, contrary to the effect observed in binary ferrites.—G. F.

Effect of Vanadium on the Properties of Cast Chromium–Molybdenum Steels. N. A. Zeigler, W. L. Meinhart and J. R. Goldsmith. (American Foundrymen's Society, 1951, Preprint No. 2). An investigation was made on (*a*) 1·25% Cr, 0·5% Mo, (*b*) 2·5% Cr, 0·5% Mo, and (*c*) 5·0% Cr, 0·5% Mo cast steels, in which vanadium ranged from 0 to 0·3% and carbon from 0·1% max. to 0·3% in each group. Results obtained in the various tests on characteristics and properties are presented. The presence of vanadium has a slight tendency to increase the thermal sluggishness and air hardenability. Increasing vanadium reduces the ferrite and pearlite grain size, produces some extremely fine spheroidal carbides, but makes the dendritic pattern more pronounced, coarse,

and persistent. In general, vanadium moderately increases the tensile strength and yield point, slightly reduces the ductility, and to a greater extent reduces the impact resistance. Metal arc welding of these steels presented no difficulty with regard to cracks and voids. Ductility of the resultant weld assemblies was somewhat decreased by the larger percentages of vanadium.—P. C. P.

Influence of Boron upon Surface Tension of 15% Cr, 25% Ni Steel. Yu. A. Klyachko, L. L. Kunin, N. S. Kreshchanovskii, and E. S. Ginzburg. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 72, No. 5, pp. 927–928). Specimens of 15% Cr, 25% Ni steel were given ferroboron additions in corundum crucibles and surface-tension measurements were made by measuring the maximum pressure in a hydrogen bubble. Boron does appear to be a surface-active substance with respect to this liquid steel. At boron contents somewhat higher than 0·06% there was a sharp drop in the surface tension of the steel. With the boron increasing to 0·1% the grain becomes finer and the columnar crystal zone narrower. With still higher boron a boron compound of eutectic character appears.

Boron Steels. R. Potaszkin. (Société Française de Métallurgie : Iron and Coal Trades Review, 1951, vol. 162, May 18, pp. 1151–1154). This article briefly reports the findings of a French commission appointed to study the effect of small additions of boron to plain carbon and various alloy steels. Boron appears to affect the conditions of austenite transformation and also the mechanical properties, particularly the tensile strength and yield ratio, which are improved when the austenite transformation takes place at temperatures less than 650° C. Boron also improves the toughness of small sections and has no adverse effect on forging properties. High-temperature tempering reduces the favourable effect of boron on the resilience of the steel.—G. F.

The Influence of Carbon, Chromium, and Tungsten Contents on the Mechanical Characteristics of Certain Valve Steels. S. Koshiba and K. Tanaka. (Tetsu to Hagane, 1948, No. 8 : Centre de Documentation Sidérurgique : Circulaire d'Informations Techniques, 1949, Aug.–Oct., pp. 395–399). Nine steels (C 0·5%, Cr 7%, W 7%, Si < 1%) were tested and found to have properties comparable with those of the more expensive high-silicon steels normally used for valves of internal combustion engines. The tests were for transformation points ; hardness, ductility, and resilience as quenched and at various tempering temperatures ; and oxidation. The quenching temperature producing maximum hardness was 1050° C., decreasing as the alloying elements were increased. In general the best sample was the one containing the least carbon.—N. McE.

You Can Save Alloy Steel by Substituting Carbon Grades and by Using Leaner Alloys. P. D. McElfish. (Western Metals, 1951, vol. 9, May, pp. 29–31). The use of plain carbon steels, and the substitution of boron-treated types is briefly discussed as a means of conserving alloying elements. Compositions of boron steels are listed, and recommended substitutions for standard grades are tabulated.—P. M. C.

Status and Development of Heat-Treating Steels. H. Kiessler. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 433–440). In order to obtain uniform properties over the whole cross-section on heat-treating, nickel and chromium alloy additions used to be employed except for small cross-sections and low strength requirements, where unalloyed steel sufficed. Increasing knowledge of the influence of alloying elements and greater certainty in heat-treating have permitted smaller and cheaper additions to be used. Development in Germany before the war was from chromium–nickel to chromium–molybdenum, and finally to chromium–manganese and manganese–silicon steels. The latest DIN (German Standard) specification allows the use of unalloyed steel for non-critical applications, manganese, manganese-silicon, and chromium steels for medium strength, chromium–molybdenum for higher strengths, and for optimum requirements in heavy sections chromium–nickel-molybdenum steels.—J. P.

Improving the Properties of Cast Iron by Modifying the Graphite. A. Guédras. (Métallurgie, 1951, vol. 83, May, pp. 351–355). The author states that he observed the nodular form of graphite in cast-iron pipes at Nancy in 1932. He discusses his investigations with Professor Girardet into the relationships between the types of graphite present in cast iron and the mechanical properties.—R. S.

Structure and Mechanical Properties of a Mo–Ni–Cr Cast Iron. E. A. Loria. (American Foundrymen's Society, 1951, Preprint No. 8). Information is given on the microstructure and mechanical properties of 1·2-in. dia. bars of a grey iron containing 2·77% total carbon, 1·40% Si, 1·40% Mo, 1·00% Ni, 0·50% Cr as cast and after tempering at 400°, 600°, and 700° F. The matrix is a mixed structure consisting mainly of acicular ferrite and a dark-etching network pattern of low-temperature transformation products (lower bainite and possibly martensite) arising from dendritic segregation of alloying elements. An as-cast tensile strength of 72,500 lb./sq. in. with a transverse strength of 5600 lb. and accompanying deflection of 0·48 in. was obtained. The tensile strength was raised to 98,300 lb./sq. in. upon tempering. The mechanical test data show that this acicular iron has an as-cast and reheat strength that is comparable with the best of the acicular irons now in use.—P. C. P.

Nickel–Molybdenum Acicular Cast Iron. (Mond Nickel Company Publication, 1951). An outline of the formation of acicular structure and the effects of alloying iron with molybdenum and nickel are given. These include exceptional strength and toughness, allied with high machinable hardness. Recommended compositions are cited. The production of castings, their heat-treatment and mechanical properties are described. Examples of applications are quoted. The production of acicular cast iron is patented. There are nine references.—T. E. D.

Acicular Cast Iron. L. Bernstein. (Gjuteriet, 1950, vol. 40, Jan., pp. 1–7). [In Swedish]. The influence of heat-treatment on the microstructure of cast iron is outlined. Suitable amounts and ratios of molybdenum and nickel additions to obtain acicular structure in castings of different thickness and the effects of silicon, manganese, chromium, and copper on the properties of molybdenum–nickel acicular cast iron are given.—B. S. E.

Investigating the Quality of Some Swedish Cast Irons. B. Tyberg. (Gjuteriet, 1950, vol. 40, July, pp. 97–128). [In Swedish]. Detailed test data of standard bars cast in a number of different Swedish foundries are given. Attempts are made to demonstrate the correlations between strength and carbon equivalent, tensile strength and hardness, and tensile strength and resistance to fracture in the Ludwik-Krystof test.—B. S. E.

Proposed Standards for Grey Cast Iron. (Gjuteriet, 1950, vol. 40, Feb., pp. 22–25). [In Swedish]. Grey cast iron of low elongation is classified into five qualities ranging from 15 to 35 kg./sq. mm. minimum tensile strength. The type of test bar to be employed is defined, and graphs showing the relationships between the properties of the test rods and those of cast products of different qualities and dimensions are to be issued.—B. S. E.

The Development of Cast Iron from a Specification Point of View. I. Forslund. (Gjuteriet, 1950, vol. 40, Sept., pp. 149–152). [In Swedish]. The history of cast iron and its standards as applied in the leading industrial countries is reviewed.—B. S. E.

Some Notes on Cast Irons for Diesel Engines. W. G. Ure. (Institute of Diesel Engineers of Australia : Australasian Engineer, 1951, May 7, pp. 73–77). The chief characteristics of cast iron are outlined, and the many uses to which it may be put in engine manufacture are discussed. Three different types of cast iron, namely 'hot-mould' iron (*e.g.*, Lanz Perlit), 'inoculated' iron (*e.g.*, Meehanite), and 'loded' all-pearlitic iron are described and their respective uses indicated. After discussing the effects of the more common alloying elements, the author gives typical compositions, mechanical properties, and applications of high-duty, austenitic, martensitic, nitrogen-hardening, and ductile cast irons.—P. M. C.

Study of the Mechanical Properties Obtained by Isothermal Quenching. R. Potaszkin and M. Jaspart. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 314–327). To determine the industrial possibilities, quenching times were limited to 1 hr. for a chromium–molybdenum steel and 6 hr. for a nickel–chromium–molybdenum steel. Of the two groups of structures (*a*) martensite and lower bainite and (*b*) middle and upper bainite, the former has greater tensile strength after low-temperature annealing and better all-round properties after high-temperature annealing. Increased carbon raises the strength of group (*a*) while chromium improves the properties of (*b*). For high mechanical properties the presence of upper bainite should be avoided.—A. G.

XUM

German and American Stainless Compared. C. A. Zapffe. (Iron Age, 1951, vol. 167, Jan. 25, pp. 56–60). A comparison of the American Iron and Steel Institute classifications for stainless steels with standards published in a Stahl-Eisen-Werkstoffblatt of April 1949 is made. Nickel in German analyses still reflects a shortage and minor manganese contents in general are lower, molybdenum is however much more widely used. Differences in stabilizing practice are discussed and various types of stainless steel compared.—A. M. F.

Nickel-Free Stainless Steels. C. B. Tupholme. (Sheet Metal Industries, 1951, vol. 28, June, pp. 541–545). The author reviews the compositions, properties, and uses of steels within the range 13 to 20% chromium and 0·03 to 0·1% carbon. For certain applications, *e.g.*, cutlery, kitchen utensils, and general and architectural fittings, these steels can replace satisfactorily the chromium–nickel austenitic stainless grades. Their mechanical properties, formability (by spinning and welding), and final polishing, are all briefly discussed.—P. M. C.

Steels from the Users' Point of View. J. Arnott. (Journal of the West of Scotland Iron and Steel Institute, 1945–46, vol. 53, pp. 10–37). The importance of corrosion resistance is stressed, and some stainless steels for use constantly immersed in water are mentioned. The effects of carbide tools and free-cutting steels on machining are reviewed with examples of machining difficulties. Problems connected with heat-treatment are not now so numerous because of automatically controlled furnaces and the intensive work on hardenability, effect of mass, and rate of cooling, which has been done. An example of vertical heating and quenching of S.11 steel shafts to get parts which did not warp during machining is quoted. The need for an impact test is stressed. Of the many brittle fractures the author has examined showing no signs of fatigue, not one had an Izod figure of over 10 ft.lb. Fatigue and methods of protection against corrosion are discussed. Freedom from corrosion in power systems is obtained by using alkaline de-aerated water, and in recirculating cooling water systems by adding 0·5% of an emulsifying oil. Special types of corrosion, such as contact and fretting corrosion are described with examples.—P. C. P.

The Homogenisation of Steel Castings and Its Influence on the Mechanical Properties. (Metal Treatment and Drop Forging, 1951, vol. 18, Apr., pp. 145–154; May, pp. 195–200). Results of work carried out by the Physical Properties Sub-Committee of the Steel Casting Division of B.I.S.R.A. are reported. For normalized plain carbon, and hardened and tempered low-alloy and cast steels of normal quality, homogenization, before the normal heat-treatment, for periods up to 30 hr. at temperatures below 1200° C. has little effect upon the tensile and Izod impact properties. The only change noted is a decrease in the yield ratio of some of the plain carbon steels. Homogenization at temperatures in the range 1200 to 1300° C. does not affect the tensile strength of the castings, but improvements in the elongation, reduction of area, and Izod impact values have been effected. After homogenization at temperatures above 1150° C., the dendritic structure, as developed by the etching reagents employed, generally becomes less marked, whilst the dark-etching cellular pattern frequently evident in the microstructure of heat-treated castings tends to be eliminated. In plain carbon steel castings of 'sub-standard' quality, homogenization at 1150° C. causes marked improvements in the elongation and reduction of area values, together with a slight increase in the Izod impact values although, again, it does not affect the tensile strength of the castings. Although the non-metallic inclusions in some of the castings have a tendency to form discontinuous chains, no changes are brought about in their distribution or shape by this treatment.—P. M. C.

METALLOGRAPHY

Metallography in Industry and Research. June A. McNicol. (Australian Institute of Metals; Australasian Engineer, 1951, Jan. 8, pp. 73–78). This is a purely descriptive and elementary account of the ranges of usefulness, and the experimental procedures of the following methods of metal examinations: Macro-etching and sulphur printing; X-ray diffraction; radiography; optical microscopy; electron microscopy; and electron diffraction.—P. M. C.

The Resources of Microradiography in Metallurgical Problems. G. A. Homès and J. Gouzou. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 251–266). Despite the lack of fineness of the image, the method is useful for the observation and identification of inclusions, the study of plastic deformation, and other applications such as the control of heat-treatment. Microradiography can be carried out by polar projection, reflection, or transparency, the latter method being described in some detail.—A. G.

Some Notes on the Barley Shell Structure in Iron–Silicon Alloys. R. V. Riley. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, May, p. 412; Journal of Metals, 1951, May). The author discusses the production of the 'barley-shell' etched structure in iron–silicon alloys, and points out that in order to produce this structure, the etching reagent must contain HF, and either the reagent or the specimen must contain silicon. He emphasizes that fresh pure reagents must be used for each etch when applying this phenomenon to distinguish between high- and low-silicon areas in specimens, as the reagent may pick up silicon from previous etches or from storage in contact with glass or silica.—G. F.

An Equipment for the Microscopic Examination of Metals and Crystals in Polarized Light at Temperatures from − 130 to + 35° C. J. C. Monier and R. J. Hocart. (Journal of Scientific Instruments, 1950, vol. 27, Nov., p. 302). An easily constructed piece of equipment is described for use with a metallurgical polarizing microscope. Provision is made for the examination of specimens so that substances with melting points as low as − 112° C. can be accurately obtained. During observation the effect of freezing on the lens or specimen is prevented.—H. D. W.

Graticules as Guides in Electron-Microscope Metallography. E. de Haas. (Nature, 1950, vol. 166, Sept. 16, pp. 482–483). **Marking Electron Micrographs.** (Industrial Diamond Review, 1951, vol. 11, June, p. 133). In the materials laboratory of the Allmäna Svenska Elektriska AB. an attachment to an ordinary microscope has been designed which allows lines less than 2 microns wide to be scratched on metallographic samples by means of a diamond.—T. E. D.

Study of Precipitates of C and N in Iron with an Electron Microscope. J. Radavich and C. Wert. (Journal of Applied Physics, 1951, vol. 22, Apr., pp. 367–371). By the use of the electron microscope it was possible to study the precipitates of carbon and nitrogen in α-iron. The physical shapes of the precipitates and the fineness of dispersion have been determined. The results of the investigation confirmed the conclusions drawn from internal friction measurements made on these alloys and reported earlier.—J. P. S.

An Improvement in the Micrography of Reheating Brittleness in Low-Alloy Steels. P. A. Jacquet. (Comptes Rendus, 1951, vol. 232, Apr. 9, pp. 1422–1424). By removing a film of cellulose acetate (formed by evaporation of a 5% solution in acetone) the products of etching attack, which conceal fine detail, are eliminated. The method, of which several examples are given, should enable structure and transition temperature to be related.—A. G.

Orientation Measurements on Large-Grained Polycrystalline Sheet. A. E. De Barr. (Sheet Metal Industries, 1951, vol. 28, July, pp. 603–607). The author briefly discusses methods available for the determination of the texture of rolled or drawn metals. The main factor influencing the choice of method is grain size, and this is discussed with reference to X-ray diffraction techniques, etch-pit reflections, and two-dimensional torque-magnetometer measurements.—P. M. C.

Structure of Spherulites in Nodular Cast Iron. H. E. Stauss, F. W. Von Batchelder, and E. I. Salkovitz. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, p. 249; Journal of Metals, 1951, Mar.). Results are presented of an X-ray study of the structure of graphite nodules in nodular cast iron, separated by electrolytic solution of the iron in hydrochloric acid. The structure is shown to be one of aggregates of graphite crystallites, in which the *c* axes of the crystallites tend to align themselves in the radial direction of the nodule, the basal planes being generally normal to the radii.—G. F.

Intergranular Energy of Iron and Some Iron Alloys. L. H. Van Vlack. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, pp. 251–259; Journal of Metals, 1951, Mar.). The author describes experiments made to determine the intergranular energy of iron and some iron alloys, the experimental procedure involving the separate determination of the relative energies of the several

interfaces in an iron/copper/copper-sulphide alloy, and of the liquid-copper/liquid-copper-sulphide interface. The energy of the γ-iron grain boundary is given as 850 ergs. sq. cm. at 1105° C., the α/α and α/γ boundaries possessing somewhat less energy. The microstructures of several iron alloys are discussed in terms of the interfacial energy relationships, and some evidence is given to show the manner in which inclusions in iron act as grain-growth inhibitors.—G. F.

Yield Phenomenon and Twinning in α-Iron. A. T. Churchman and A. H. Cottrell. (Nature, 1951, vol. 167, June 9, pp. 943–945). At − 190° C. the yielding of single crystals of Armco iron (0·02% C) is replaced by deformation twinning on four different $\{111\}$ planes with eventual cleavage fracture. Thorough elimination of carbon and nitrogen or previous deformation produces slip at the same temperature. These results are explained on the basis of the unusually strong dependence of the upper yield stress on temperature.—A. G.

Epitaxial Growth of Crystals of Ferric Oxide by Controlled Oxidation of Iron at High Temperatures. J. Bénard and J. Bardolle. (Comptes Rendus, 1951, vol. 232, June 11, pp. 2217–2218). Controlled oxidation at 850° C. (1) favours an orientation relationship between oxide and metal, (2) permits the development of an epitaxial layer with characteristic geometrical forms, and (3) reveals important differences in the speed of growth.—A. G.

Optical Methods in X-Ray Analysis. I—The Study of Imperfect Structures. C. A. Taylor, R. M. Hinde, and H. Lipson. (Acta Crystallographica, 1951, vol. 4, May, pp. 261–266). Illustrations are given of the application of the method to the transition from the cubic to the hexagonal closely packed structure, and the ordering process in alloy $AuCu_3$. From the latter investigation it would appear that the X-ray diffraction effects observed can be accounted for entirely by changes in the degree of short range order. Some rules are given for guidance in the interpretation of the X-ray patterns of imperfect structure.—E. T. T.

A Modification of the Cohen Procedure for Computing Precision Lattice Constants from Powder Data. J. B. Hess. (Acta Crystallographica, 1951, vol. 4, May, pp. 209–215). The Cohen scheme for weighting the measurements upon the lines of powder patterns is shown to be inappropriate, and a modified weighting is proposed. Examples are given to illustrate the improvement in precision resulting from the modified method. Further practical confirmation has been indicated from many hundreds of lattice constant determinations by the modified computation, which have been made in the Magnesium Laboratories of the Dow Company. The slightly greater computational effort required for the modified procedure has been completely justified by improvement in the precision of the computed lattice constants.—E. T. T.

Dynamical Theory of Electron Diffraction for a Finite Polyhedral Crystal. N. Kato and R. Uyeda. (Acta Crystallographica, 1951, vol. 4, May, pp. 227–231). In Part I the authors show that Bethe's dynamical theory of electron diffraction can be extended to the case of a finite crystal. In Part II they develop the theory further and compare its results with those derived from the kinematical theory. Although their theory disregards the effects of inelastic scattering, it may be useful to interpret the fine structure and anomalous intensity observed in the electron-diffraction patterns, and it may serve also for a better understanding of results observed in electron micrographs and diffraction patterns of convergent electron beams.—E. T. T.

Phase-Limiting Relations Following from a Known Maximum Value of the Electron Density. R. Pepinsky and Caroline H. MacGillavry. (Acta Crystallographica, 1951, vol. 4, May, p. 284). The usefulness of inequalities for phase determination depends strongly on the relative largeness of the zero term in Fourier expansion compared with the other terms. It seems that inequalities derived might be useful in those projections where there is considerable overlap, such that average projected electron density $F_{000}.c/V$ lies closer to R' than zero (c = period of axis of projection). R', the maximum value of the projected electron density, can be estimated from the size and electron distribution of the individual atoms and the period of the axis of projection.—E. T. T.

Electron Diffraction Study of the Cementation of Iron. J. J. Trillat and S. Oketani. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 289–295). Films of iron were prepared by evaporation on to the (200) face of a rock salt crystal. During cementation by pure carbon monoxide Fe_3C appears at 400° C. together with Fe_3O_4. Above 710° graphite appears and at 800° C. the surface is all graphite and Fe_3O_4. In case-cementation no iron carbide was formed. Using a mixture of CO and hydrogen no oxide was observed at 500° while at 350° annuli corresponding to the structure Fe_2C appeared.—A. G.

On the Question of the Structure of Iron Films Deposited from the Vapour Phase. C. Heck. (Zeitschrift für Metallkunde, 1951, vol. 42, Jan., pp. 10–13). H. König, who deposited iron films by evaporation *in vacuo* from piano wire, found that if the films were deposited on to a collodium or aluminium oxide base at room temperatures unexpected irregularities appeared in the electron diffraction photographs of the deposited metal, such as the non-appearance of a diffraction pattern due to the (310) plane of the body-centred structure. The author shows that these irregularities disappear completely if it is assumed that the structure of the thin films is of the face-centred gamma type, not body-centred. If the thickness of the film is increased the new layers eventually take on the body-centred structure in which polycrystalline iron normally exists at these temperatures. The body-centred structure also appears on heating a thin film having the face-centred structure to about 150° C.—P. F.

On the Crystal Structure and the Particle of the Carbide Phase in Tempered Steel. M. P. Arbuzov. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 73, No. 1, pp. 83–86). Measurements were made of the line widths in X-ray photograms of carbide residues isolated from steels containing 1% carbon and tempered at 50° C. intervals in the 100–700° C. range. Transition from higher to lower tempering temperatures is accompanied by a gradual widening of photogram lines. The transition from the low-temperature state of the carbide phase (called Fe_xC by the author) to ordinary cementite is not accompanied by any change in the crystal lattice of the carbide.

Condition of Martensite Electrolytically Isolated from Quenched Steel. M. P. Arbuzov. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 74, No. 6, pp. 1085–1087). Specimens of quenched steel containing 0·80, 0·98, 1·16, 1·38, and 1·51% of carbon were dissolved and deposits of martensite powder obtained; these were studied by X-ray diffraction. It was found that the crystal structure of martensite does not change when the steel is dissolved. After separation of the single crystals of martensite they are almost entirely free from lattice distortion which causes the interference lines to be diffuse.—R. A. R.

Use of the System of Lattice Units in the Presentation of Isothermal Reaction Curves. L. C. Corrêa da Silva. (Boletim da Associação Brasileira de Metais, 1950, vol. 6, Apr., pp. 77–85). [In Portuguese]. Based on a relationship between the coefficient of diffusion of carbon in the austenite and the average frequency of the jumps of the carbon atoms in the austenite network, a new unit of time is defined which can be used in presenting **S**-curves to eliminate the effect of the variation of the coefficient of diffusion with temperature. The elimination of this effect is an essential step in the eventual interpretation of the curves. It was confirmed that, at 1000° C., each atom of carbon in the austenite oscillated $2{\cdot}7 \times 10^9$ times/sec. The unit of time is defined as the average time between two successive jumps (oscillations) of a carbon atom. The **S**-curve thus suggests that: (1) As the temperature decreases, a given decomposition reaction of austenite requires less rearrangement of the atoms to originate it; and (2) of the various reactions possible at a given temperature, the one which takes place is that involving the least atomic rearrangement.—R. S.

A New Method of Making Alloy Powders for the Determination of Phase Boundaries of Metallic Systems. F. Lihl. (Metall, 1951, vol. 5, May, pp. 183–187). The author points out that the commonly adopted method of determining the equilibrium diagram from the study of alloys either cooled or heated to a given temperature is liable to give false results at temperatures below 300–400° C. owing to the difficulty of attaining thermodynamic equilibrium. This difficulty is overcome if the alloy is formed at the temperature in question. The author's method is to mix suitable chemical compounds of the constituents of the alloy, which may be reduced thermally or chemically at the temperature in question so that the pure metals thus obtained are alloyed at that temperature. The phase boundaries are then determined by X-ray examination. The author has explored the possibilities of the method

for the Fe–Ni, Co–Ni, and Co–Fe systems, using formates of the metals which decompose in the region 215–240° C. He finds that in each case the mixed phase regions are wider, those of the high-temperature phase narrower, and the phase boundaries less steep than is found in the literature.—J. G. W.

Isothermal Transformation Diagrams for Nickel Steels. (Mond Nickel Co. Ltd., London, 1951). To obtain data for the determination of isothermal transformation diagrams, the dilatation method was used in conjunction with examination of the microstructure. The general features and interpretation of the diagrams are described. All the common alloying elements, except cobalt, delay the initiation and decrease the rate of transformation. The martensite reaction and the occurrence of retained austenite are examined in some detail. Numerous limitations in the use of these diagrams are discussed and three special heat-treatments, namely martempering, austempering, and isothermal annealing, which have been evolved from isothermal transformation diagrams, are described. Diagrams are included for 13 nickel, nickel–chromium, nickel–chromium–molybdenum, and nickel–molybdenum steels.—T. E. D.

Phase Diagrams. E. H. Bucknall and P. Hersch. (Institute of Metals Symposium on the Investigation of Alloy Systems : Metal Industry, 1951, vol. 78, June 1, pp. 443–446). The authors outline briefly the principles of phase diagrams, and show how phase-diagram study can contribute to the improvement of metallurgical practice. Stress is laid on the special care needed in presenting and using phase diagrams for systems with volatile components.—P. M. C.

The Approach of Alloys to Equilibrium. D. McLean. (Institute of Metals Symposium on Investigation of Alloy Systems : Metal Industry, 1951, vol. 78, May 18, pp. 349–402). The approach of alloys to equilibrium, which involves the appearance or disappearance of the phases which exist under a certain set of conditions, is considered from the point of view of its intimate association with precipitation and resolution. Nucleation and growth rates are discussed with reference to the influencing factors diffusion, binding energy, and statistical fluctuations. Critical nucleus size is also discussed.—P. M. C.

General Remarks on Reactions in Solid Metals. L. C. Corrêa da Silva. (Boletim da Associação Brasileira de Metais, 1950, vol. 6, Apr., pp. 179–192). [In Portuguese]. Thermodynamic factors determining the limits of phase stability and their influence in the case of reactions in the metastable field are considered. A classification of solid metal reactions is suggested.—R. S.

Vanadium–Oxygen Equilibrium in Liquid Iron. J. Chipman and M. N. Dastur. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 191, pp. 111–115 ; Journal of Metals, 1951, Feb.). The authors describe an experimental study of molten iron–vanadium alloys containing 0·03–1·3% V., brought into equilibrium with controlled atmospheres of water vapour and hydrogen at 1600° C. When the gas mixture is sufficiently oxidizing, an oxide film forms on the metal surface, consisting of V_2O_3 when the melt contains more than 0·30% V, and of the spinel $FeO.V_2O_3$ when the melt contains 0·10% V. The thermodynamic behaviour of the systems is dicussed, and a deoxidation diagram is presented in which two lines represent the percentage and activity of oxygen in the alloy respectively. The slope of each line changes at 0·17% V, the solid phase above 0·17% V being V_2O_3, and below it, $FeO.V_2O_3$.—G. F.

Formation and Behaviour of Subboundaries in Silicon Iron Crystals. C. G. Dunn and F. W. Daniels. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 191, pp. 147–154 ; Journal of Metals, 1951, Feb.). This paper describes an investigation of sub-boundary phenomena in a high-grade commercial silicon iron containing 3·3% Si. Micrographic and X-ray examinations of plastically deformed single crystals show that the removal of asterisms in Laue spots is caused by two processes: (*a*) Polygonization, producing a relatively fine sub-grain structure, which occurs in bent single crystals with sub-boundaries at 90° to the active slip plane ; and (*b*) a fairly uniform sub-grain growth, producing a more nearly perfect single crystal of low sub-boundary energy. Annealing of two-grain specimens at high temperatures shows that, when one grain alone contains sub-boundaries, the other grows quite readily, whilst, when both grains contain sub-boundaries, the ordinary boundary sometimes fails to move, but the sub-grains grow larger.—G. F.

The Equilibrium Diagram of the System Iron–Zinc. G. V. Raynor. (Institute of Metals, Annotated Equilibrium Diagrams, 1951, No. 8, June). The most probable composite diagram for the Fe–Zn system, based on reliable and recent work, is given. Numerical data are presented in a table, which gives authorities and estimated accuracies. There are 33 references.—T. E. D.

Microscopical Studies on the Iron–Nickel–Aluminium System. Part II—The Breakdown of the Body-Centred Cubic Lattice. A. J. Bradley. (Journal of the Iron and Steel Institute, 1951, vol. 168, July, pp. 233–244). Part I dealt with $\alpha + \beta$ alloys and isothermal sections of the phase-equilibrium diagram (*see* Journ. I. and S.I., 1949, vol. 163, Sept., p. 19). Body-centred cubic alloys of the Fe–Ni–Al system may be classified as either β disordered or β' ordered like NiAl. A very narrow two-phase gap may be traced from the melting point downwards, which does not open appreciably above 1000° C. From 950° C. to 750° C. a rapid change takes place. In each isothermal section (950° C., 850° C., 750° C.), the β and β' region constitutes a bay which quickly increases as the temperature is lowered. Contrary to the experience of earlier investigators, these alloys give rise to microsections which are readily recognized under oil immersion. Three main types of duplex alloy have been identified. In one, an ordered lattice is precipitating from a disordered lattice. At low temperatures islands of order are formed within the mosaic structure and these stack together in small units to form cubes of the ordered lattice. Sometimes the corners of the cubes are rounded, or they may even form perfect spheres instead. In another type of structure disordered matter is being ejected from each mosaic cell, leaving the interior completely ordered. The ejected matter is first deposited at each corner of the mosaic, and then joins together neighbouring corners to form a continuous network. These two types of structure are formed when the disordered or ordered structures are in considerable excess. When approximately equal amounts of the two phases are present, a lamellar tetragonal structure is formed on 001 planes, analogous to that previously found for FeCuNi, from X-ray evidence. With excess of iron, the ordered NiAl bands break up into cubes or spherules. With less iron, the disordered iron bands are no longer continuous, and in section a maze-like structure is produced. The approximately pseudo-binary sections, in which these structures are mainly to be found, contain, for the most part, slightly more Al than the vertical plane Fe–Ni–Al. With more Ni, three-phase structures are formed, showing a characteristic combination of the $\beta + \beta'$ with the $\alpha + \beta$ or $\alpha + \beta'$ patterns. The pseudo-binary planes are twisted, so that the exact positions of phase boundaries require extremely careful delineation.

The System Iron–Phosphorus–Cobalt. J. Berak. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 131–135). The Fe-Fe_2P–Co_2P–Co portion of the Fe–P–Co system has been examined by thermal, structural, and X-ray methods, and the phase diagram derived. Fe_2P and Co_2P form two series of solid solutions, separated by a narrow heterogeneous field. It is shown that the compound Co_3P does not occur. There is an equilibrium line from Fe_3P in the direction of the assumed compound Co_3P, but it proceeds only as far as 33% Fe. The $(Fe,Co)_3P$ solid solutions are stable from their freezing points down to 800° C., below which they decompose into an α- and a $(Fe,Co)_2P$ solid solution. The results indicate that there is very little difference between the affinities of iron and cobalt for phosphorus.—J. P.

Constitution of Iron–Chromium–Molybdenum Alloys at 1200° F. S. R. Baen and P. Duwez. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, pp. 331–335 ; Journal of Metals, 1951, Apr.). The phase boundaries of the Fe–Cr–Mo ternary system have been determined at 1200° F., the identification of phases and determination of phase boundaries being based on X-ray diffraction measurements and microscopic observation. The brittle σ and ϵ phases are shown to extend over a major portion of the diagram, the largest one-phase solid solution region being located near the chromium corner.—G. F.

CORROSION

The Resistance of Steel Structures to Corrosion. A. Roggeveen. (Ossature Métallque, 1950, vol. 15, Sept., pp.

388–389). The maintenance required by steelwork on the interior and exterior of buildings is discussed. When the atmosphere is not wet or corrosive the steel may last almost indefinitely without attention.—N. MCE.

Research on Corrosion in the United States. M. Pourbaix. (Association des Gaziers Belges : Ossature Métallique, 1950, vol. 15, Nov., pp. 524–529). After emphasizing the great losses caused by corrosion. the author sums up the present position as being marked by : (1) A growing use of good rather than cheap practices, *e.g.*, the use of non-corroding metals, paints, inhibitors, zinc or magnesium anodes or electrical means ; (2) greater co-operation between the various organizations involved ; and (3) a sudden interest in fundamental research. The bearing of electrochemistry is pointed out in some detail. The list of problems in hand at present includes studies of complex equilibria, production of an atlas of electrochemical equilibrium diagrams, electrochemical reduction of oxygen, stability of oxygenated water, and theories of passivity.—N. MCE.

Stress-Corrosion Tests on Turbo-Supercharger Materials in the Products of Combustion of Leaded Gasoline. G. B. Wilkes, jun. (Symposium on Corrosion of Materials at Elevated Temperatures, June 26, 1950 ; American Society for Testing Materials, Special Technical Publication No. 108, pp. 11–25). *See* Journ. I. and S.I., 1950, vol. 166, Dec., p. 389.

Hydrogenizing Effect of Steam on Ferrous Alloys at Elevated Temperatures. C. A. Zapffe and F. K. Landgraf. (Symposium on Corrosion of Materials at Elevated Temperatures, June 26, 1950 ; American Society for Testing Materials, Special Technical Publication No. 108, pp. 50–58). **Embrittling Effect of Steam on Stainless at Elevated Temperatures.** C. A. Zapffe and F. K. Landgraf. (Steel, 1951, vol. 128, Apr. 30, pp. 54–57, 81–82). The authors report the effect of steam on various grades of stainless steel, including types 403 and 410, used for steam turbines, the relatively non-hardenable type 430, and types 414 and 440, which are hardenable stainless steels. A specially designed bend test is used to compare the bendability after quenching from dry air or helium furnace atmospheres with that from wet atmospheres. Embrittlement occurred in all cases in wet atmospheres, exposure for 1 min. to steam at the end of heat-treatment producing a marked effect. Ageing steam-embrittled samples in hot glycerine leads to recovery; type 410, with bendability reduced to 20°, aged for 2 hr. at 170° C., recovers completely. Ageing in air for two months leads to a similar recovery.—T. E. D.

Oil Ash Corrosion of Materials at Elevated Temperatures. C. T. Evans, jun. (Symposium on Corrosion of Materials at Elevated Temperatures, June 26, 1950 ; American Society for Testing Materials, Special Technical Publication No. 108, pp. 59–113). *See* Journ. I. and S.I., 1950, vol. 166, Dec., p. 387.

Corrosion and Passivation of Mild Steel at High Speeds of Movement in Aqueous Solutions. F. Wormwell and H. C. K. Ison. (Chemistry and Industry, 1950, July 8, pp. 549–550). The results obtained with a rotor apparatus for studying corrosion at high speeds, using sodium chloride solutions, are discussed. Passivation is said to be due to the rapid access of oxygen, which keeps the protective film in repair. The spread of the results for the longer periods of immersion is thought to be due to the varying tendency of the scale to flake off.—N. MCE.

Intercrystalline Corrosion of Alloys. G. V. Akimov. (Magyar Kémiai Folyoirat, 1951, vol. 57, June, pp. 179–189). [In Hungarian]. This is a translation of a paper published in Izvestiya Akademii Nauk, Chemical Series, 1951, No. 13. Different types of corrosion are briefly described and the influences of the individual types on the loss of strength are given shown by curves. Intercrystalline corrosion is dealt with in greater detail, giving recent Russian theories and research results. The main factor influencing intercrystalline corrosion is the distribution of the electrical potential in the individual parts of the structure ; the grain boundaries act as anodes whilst the grain substance and inclusions act as cathodes ; in more complex systems there may also be secondary couples. The author has investigated various structure systems and a comparison of the calculated and measured electrical values for a Cu–Pt–Fe–Zn system is made. The electrode potentials of corrosion-resistant steels and Duralumin after various heat-treatments were also studied. A method of analytical investigation of the polarization in complex systems was developed as a result of research work by the author, I. E. Levin, and G. B. Clark in 1944–48. Measurement of the potential distribution of a structure was carried out by microelectrochemical methods applying a microscope and a capillary 3 to 10 microns in dia. mounted on a micromanipulator. A new improved method is described in which polarization curves are constructed from measurements using a specimen with and without a coating of insulating varnish on the grain boundaries. The author concludes that changes on the grain boundaries during heat-treatment have a decisive effect on intercrystalline corrosion ; he presents data and suggests practical measures for reducing the danger of intercrystalline corrosion of 18/8 steel and Duralumin.—E. G.

Study by X-Ray Diffraction of Selective Oxidation of Nickel–Iron Alloys. J. Moreau and J. Bénard. (Comptes Rendus, 1951, vol. 232, May 16, pp. 1842–1843). During oxidation the metallic phase immediately in contact with the oxide layer becomes enriched in nickel at a rate dependent on temperature. This is due to the instability of NiO in the presence of FeO which, because of its non-stoichiometric nature, acts as a vehicle for iron.—A. G.

A New Instrument for Measuring Galvanic Corrosion Currents. H. P. Godard. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Apr., pp. 276–282). Previous determinations of currents by the measurement of potential difference gave low values due to the effect of the external resistance. To eliminate this a circuit with a nul resistance ammeter has been developed and practical applications are given.—A. G.

The Corrosion of Steel by Electrolytes Used in Chromium Plating Plants. L. Koch. (Metalloberfläche, 1950, vol. 4, May, pp. A65–A68). The paper reports the results of a metallographic examination of three badly corroded steel parts from a chromium plating bath. It is concluded that the corrosion is caused by a grain-boundary attack due to preferential solution of cementite which enables the plating solution to penetrate round ferrite grains and to disintegrate the steel or to make it porous. It is concluded that this form of corrosion can be avoided by the use of (*a*) low-carbon or carbon-free iron ; (*b*) surface-decarburized steel ; or (*c*) steel heat-treated so as to consist of granular pearlite. These conclusions have been confirmed by laboratory tests on five samples containing from less than 0·05% to 0·45% carbon. Both the weight loss and the depth of penetration increased with increasing carbon content.—O. H. G.

The Corrosion Resistance of Hard-Chromium Layers. H. W. Dettner. (Metalloberfläche, 1950, vol. 4, Mar., pp. A33–A37). The paper describes experiments designed to test the corrosion resistance to concentrated H_2SO_4, concentrated HNO_3, 25% formic acid, 80% acetic acid, 3% sodium chloride, 40% caustic potash, and 10% ammonia, of specimens chromium-plated in a bath containing 250 g. CrO_3/litre and 1% H_2SO_4 at temperatures between 30° and 70° C., using current densities between 0·2 and 0·8 amp./sq. cm. Specimens plated between 45° and 53° C. have the smallest resistance to corrosion towards the acids and the salt solution, both specimens plated at higher and lower temperatures giving better results. At temperatures above 53° C. a decrease in current density leads to a better corrosion resistance, below 45° C. the reverse is the case. This difference in behaviour is attributed to different proportions of α- and β-chromium in the chromium layers. All the specimens gave good results in tests with the alkaline solutions.—O. H. G.

The Scaling Process and Accelerated Life Testing of Heating-Element Alloys. H. Krainer, L. Wetternik, and C. Carius. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 103–110). The mechanism of scaling of heat-resistant steels and heating-element alloys is discussed and experiments described in which a 25/20 Cr–Ni steel, and 80/20 Ni–Cr alloy and a 24/5·5 Cr–Al steel were subjected to scaling in air at various high temperatures, under which conditions the scale on the first sample consisted of a chrome spinel and chromic oxide, that on the second of chromic oxide and that on the third of alumina. The parabolic time law was obeyed approximately by the Ni–Cr alloy ; with the other materials the exponent was of the order of 2·5–3·0. The resistance to alternating temperature differed markedly with the three alloys ; the chromic oxide film exhibited the best resistance and the alumina film the worst. The resistance to alternating temperature could be improved by small additions of other elements to the alloys or by surface treatment with thorium nitrate solution. This fact may be of importance in the development of heat-resistant alloys. Experiments showed that there was no simple correlation between scaling

rate and useful life as measured by accelerated alternating heating tests on helically wound heaters. Some of the problems connected with optimum wire thickness, test period and reproducibility in accelerated life-testing are discussed. A procedure for determining the temperature of heating helices is described.—J.P.

Impact Deposition of Atmospheric Sea Salts on a Test Plate. A. H. Woodcock. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 1151–1160). This study was carried out at Block Island, R.I. Test slides of different size were used to investigate the deposition of aerosols by impact, and it was found that deposition was far more rapid on a smaller surface, and the difference in rate became less with increasing weight of nuclei deposited. Other important factors were humidity, wind speed and direction, and roughness of surface. The results might be used to explain 'edge corrosion' of exposed steel plates.—T. E. D.

Spray Testing with Natural and Synthetic Sea Water. Part I—Corrosion Characteristics in the Testing of Metals. T. P. May and A. L. Alexander. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 1131–1149). A new formula is proposed for synthetic sea water, with exact reproduction of ion concentrations above 1 p.p.m. which do exist in natural ocean water. Provision is made for adjustment of *p*H and for the addition of heavy metal ions. Spray tests were conducted upon a number of metals using natural sea water, synthetic sea water, and 3% and 20% NaCl solutions. The same metals were also exposed in the atmosphere and in sea water at Kure Beach, N.C. There was little similarity of performance between the natural environments and the spray cabinets using NaCl solutions, the only exception being in the case of the deterioration of nickel-plated steel. With ingot iron and plain steels, none of the spray tests duplicated the natural marine tests. Zinc-plated steel and solid zinc sheet corroded similarly in the spray cabinets using natural and synthetic sea water and in the marine environments. The corrosion rates were not sufficiently high to be considered as accelerated tests.—T. E. D.

Corrosion of Steel in Laminar Flowing Water. J. L. Mansa. (Acta Chemica Scandinavica, 1950, vol. 4, pp. 1263–1274). The formation of a rust layer upon an iron surface overflowed by water was investigated, a special test cell with laminar flow being constructed for the purpose. Copenhagen tap water was used for the tests.—T. E. D.

ANALYSIS

Chemical Spectroscopy. W. R. Brode. (Proceedings of the American Society for Testing Materials, 1950, vol. 50, pp. 513–559). In this survey two separate fields of chemical spectroscopy are discussed, emission and absorption. In the emission field, qualitative and quantitative elemental analysis is considered, and in the absorption, the infrared, visual, and ultraviolet spectra as applied to the identification of atomic combinations and of molecules.—T. E. D.

Spectrographic Analysis of Welds. A. Camuñas Puig and E. A. Alvarez-Arenas. (Instituto de la Soldadura, Publication No. 17, 1951, pp. 5–16). [In Spanish]. Local spectrographic analysis is classified as qualitative or quantitative. Each of these two classes is divided into macro and micro methods. The principles of these methods are described and their application to the hard-facing of a gear tooth, the defective weld of a supporting ring, and to stainless welds are discussed.—R. S.

Survey of Methods for Aluminium Determination and a Disinvolved Phosphate Method Applicable to Iron Ores and Analogues. E. T. Saxer and E. W. Jones. (Blast Furnace and Steel Plant, 1951, vol. 39, Apr., pp. 445–450, p. 476; May, pp. 549–552). The determination of alumina in iron ores by conventional phosphate methods is discussed and criticized. Details are given of an improved method. The alumina is precipitated as the phosphate in the presence of P, Si, Cr, and As after the separation of Fe, Mn, Ti, Zr, Ca, and Mg. For ten determinations of a sample containing 1·91% Al_2O_3 the average percentage of Al_2O_3 found was 1·93%.—J. P. S.

Rapid Photometric Determination of Cobalt in Steel. E. Piper and H. Hagedorn. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Mar.–Apr., pp. 99–101). A rapid method, suitable for the melting-shop laboratory, is described for the estimation of cobalt in steels. It depends on oxidizing the cobalt, after solution of the steel in H_3PO_4–H_2SO_4–HNO_3, with $K_3Fe(CN)_6$ in ammoniacal citrate solution and determining the extinction coefficient of the orange-red coloration at 500 mμ. The blank is the same solution without the addition of the $K_3Fe(CN)_6$. The determination is not affected by the presence of iron or the usual alloying elements, except when chromium or copper are present in large amounts. A ZnO separation is then recommended. The normal method requires 15–20 min.—J. P.

A Review of Flame Photometry. V. W. Meloche. (American Society for Testing Materials, 1951, Preprint No. 126). This survey of a method of chemical analysis deals with the development of technique, flame excitation, use of the spectrophotometer, and advantages and limitations of flame photometry. Particular attention is paid to filter photometers, pressure regulators, atomizers, flames, and detectors of radiation, with a section on the elimination of the various sources of interference.—E. T. L.

Analysis of Inclusions. M. Lacomble and J. Varetto. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 199–204). The determination of inclusions by anodic solution (using an electrolyte with 100 g. sodium chloride, 10 g. potassium bromide, and 50 g. sodium citrate per litre), and by extraction with aqueous and alcoholic-iodine solution has been studied and the schemes of analytical separation used are given. Only anodic solution leaves all the inclusions intact. Iodine extraction dissolves part of the combined FeO and MnO.—A. G.

The Application of the Reducing Properties of Chromous Salts to Analysis. R. Pallaud. (Chimie Analytique, 1951, vol. 33, June, pp. 181–185). Aqueous solutions of chromous chloride or sulphate possess a power of reduction superior to that of solutions of titanous chloride. Details are given for the preparation of the solutions. A potentiometric end-point is most satisfactory for most titrations in which chromous salt solutions are employed. Practical applications include the determination of ferric iron, mixtures of iron and copper, antimony, antimony and tin, copper and tin, bismuth and tin, mercury, silver, gold, oxygen, and some organic compounds. T. E. D.

A Method for Determining Tantalum in Stainless Steels. M. F. Hasler. (Applied Research Laboratories, Glendale, California, 1950, June 12). A spectrochemical method of determining 0·02–1·0% Ta in stainless steels, with a moderate degree of accuracy, is described. The method depends on getting a very arc-like discharge between a flat sample and a graphite counter-electrode. In this way interference by the spark chromium line, 3310·6 Å. on the most sensitive arc tantalum line, 3311·2 Å., is eliminated and good sensitivity is obtained.—T. E. D.

Analysis of Stainless Steels Covering Wide Ranges of Composition by Means of the ARL Quantometer. (Applied Research Laboratories, Glendale, California, 1950, Aug. 14). A spectrochemical method of analysis for stainless steels is described. The elements and the ranges of concentration investigated are: 50·0–85·0% Fe, 10·0–30·0% Cr, 0·1–25·0% Ni, 0·1–20% Mn, 0·1–1·0% Si, 0·1–2·5% Mo, 0·1–2·0% Ti, 0·1–1·0% Cb, and 0·5–2·0% W. The method employs the point-to-plane sparking technique, with the sample cut to provide a flat ground surface.—T. E. D.

Analysis of Tool Steels by Means of the ARL Quantometer. (Applied Research Laboratories, Glendale, California, 1950, Oct. 20). A spectrochemical method of analysis employing the point-to-plane sparking technique has been developed for high-speed tool steels. The elements and the ranges of concentration investigated are: 60·0–85·0% Fe, 1·0–20·0% W, 0·1–10·0% Mo, 0·05–5·0% Cr, 0·1–5·0% V, 0·1–1·0% Mn, 0·1–1·0% Si, and 0·05–0·25% Ni. Working curves for these elements are included.—T. E. D.

Micrographic Quantitative Analysis of Ternary Alloys. S. Amari. (Metallurgia Italiana, 1951, vol. 43, Jan., pp. 6–12). Consideration is given to alloys having complete solubility in the liquid state and partial solubility in the solid state. Differentiation is made between alloys with one, two, and three components. A description is given of detailed investigations carried out on the ternary diagram of constituents and on the concentrations obtaining. The application of quantitative micrographic analysis to these investigations is described.—M. D. J. B.

New Method for Speeding up the Determination of the Manganese Content of Slags, Ores, Refractories, Water. I. Sajó. (Öntöde, 1951, vol. 2, Feb., p. 44 : Kohászati Lapok, 1951, vol. 6, Feb.). [In Hungarian]. A method is described which permits the manganese content in ores, slag, and refractories to be determined in 20 to 25 min. particularly if the content is below 1%.—E. G.

The Analysis of Variance in a Sampling Experiment. W. M. Bertholf. (American Society for Testing Materials, 1951, Preprint No. 125). A complete set of equations is given for computing the various sums of squares of deviations about the several means of an experiment involving a number of increments of varying weight, taken in close order within groups but with an appreciable interval between groups.—E. T. L.

Coal Sampling Problems. A. A. Orning. (American Society for Testing Materials, 1951, Preprint No. 124). This is a statistical consideration of the necessary conditions of satisfactory coal sampling, bearing in mind the variable ash and moisture contents differing between lumps. The error of sampling of a coal is roughly given by the ratio of maximum lump weight to the sample weight.—E. T. L.

INDUSTRIAL USES AND APPLICATIONS

Crusher Plates for Diamonds. R. S. Young. (Journal of Metals, 1951, vol. 191, Feb., p. 97). The author briefly describes the results obtained with crusher plates of various materials in the crushing of 'boart,' the lowest-priced category of industrial diamonds for use in drill bits and grinding wheels. The usual unalloyed white cast-iron plates wore rapidly and crushed only 50,000 carats before replacement. Manganese steel plates (13% Mn) crushed 900,000 carats before replacement, but had the disadvantage that abraded steel particles, being non-magnetic, could not be removed by a simple magnetic separation. The best results were obtained with Ni-Hard, a white cast iron (4·25% Ni, 1·75% Cr), the plates crushing 1,000,000 carats before replacement, with the added advantage that the abraded metal particles could be removed magnetically.—G. F.

The Choice of Steel Quality for the Oil and Allied Industries. W. P. Kerkhof, H. G. Geerlings, and H. v.d. Haas. (Lastechniek, 1951, vol. 17, Mar., pp. 33–37; Apr., pp. 57–63; May, pp. 78–82). [In Dutch]. Important factors affecting the choice of material for the oil industry are discussed. Corrosion and associated welding properties are dealt with. Strength and impact resistance and high temperatures are considered in relation to a more exact determination of the permissible stresses. Recent theories in the field of rupture hypothesis are outlined. The theories of Bailey, St. Venant, and Söderberg on the relations between multi and uni-axial stresses and plastic strain are examined.—R. S.

The Tube As a Structural Element in Structural Steel Engineering. E. M. Hünnebeck. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 449–454). The application of steel tubes as girders, in bridges, derricks, gantries, and roofs, is described and illustrated.—J. P.

Crude Gas to Finished Product. 4—Cast Iron Renatus. (Gas Times, 1951, vol. 67, June 15, pp. 509–510). The product obtained by adding certain metals, *e.g.*, magnesium, or cerium, to molten iron before casting combines the resistance to corrosion inherent in cast iron with the strength and toughness of steel. The flake graphite, found in ordinary grey cast iron, is a source of embrittlement, whereas the spherical shape of the graphite which is induced by the new process eliminates the planes of cleavage otherwise present. Within the gas industry immediate applications of this material would appear to be for retort door fastenings, pump impellers, gears, exposed couplings, elevator buckets, chair conveyors, coke extractors, and gasholder guide carriages. —T. E. D.

HISTORICAL

The Development of the Bessemer Process in Lancashire, 1856–1900. W. M. Lord. (Transactions of the Newcomen Society, 1945–46 and 1946–47, vol. 25, pp. 163–180). A survey of Lancashire pig-iron production and early refining methods is followed by details and a drawing of Bessemer's fixed converter of 1856. The development of the process and the quality of the steel produced are outlined.—T. E. D.

Northumberland Blast Furnace Plants in the 19th Century, T. M. Hoskison. (Transactions of the Newcomen Society, 1945–46 and 1946–47, vol. 25, pp. 73–81). The two furnaces in the county in 1800 had increased to 16 by 1855, but declined to 3 in 1891. Stack heights increased from about 40 ft. to 70 ft. during the century, and production from 30 tons to 700 tons/furnace/week. Details of plant and production during the period are given.—T. E. D.

MISCELLANEOUS

Use of Radioactive Elements for the Study of Steels and Industrial Metallurgical Processes—Applications to the Study of Segregation. A. Kohn. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 219–235). These elements may be applied to problems in ferrous metallurgy such as : (1) The speed of autodiffusion of iron, (2) the distribution of lime between liquid steel and slag, (3) the origin of sulphur in metallurgical coke, (4) time of transit of gas in the blast-furnace, and (5) the tantalum content of ferroniobium. The conditions of use and methods of detection are described with a detailed account of the autoradiographic determination of segregation in metals.—A. G.

Processing Metals with Atomic Energy. T. A. Dickinson. (Steel Processing, 1951, vol. 37, May, pp. 221–225, 257). A brief review is given of the many and varied problems connected with metals, to which radioisotopes are being applied. Process control of steelmaking processes, dry friction and lubrication studies, measurement of metallic vapour pressures, and solid diffusion studies are several examples quoted by the author. There are 16 references.—P. M. C.

Preparation of Very Fine Wire by Electropolishing. W. H. Colner, M. Feinleib, and H. T. Francis, (Metal Progress, 1951, vol. 59, June, pp. 795–797). Fine wire prepared by drawing is expensive, so the method described here was evolved to produce stainless-steel wires down to 0·00015 in. in dia. Owing to the large surface/volume ratio of fine wire, the length of the electropolishing section was within 2 in. of the solution surface, so a uniform etch was achieved by passing the wire slowly through the surface of a phosphoric acid solution. The eventual fineness of the wire depends on its speed and the polishing current, once the solution composition and temperature are fixed.—E. T. L.

The Functions of Professional Research Organisations, and in Particular of L'Institut de Recherches de la Sidérurgie. H. Malcor. (Société des Ingénieurs Civils de France, 1951, Bulletin No. 8, pp. 116–121).—T. E. D.

Post-War Development of Industrial Psychology in Germany. E. Bornemann. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 457–465). An attempt is made to review the most important tasks of industrial psychology and, from the abundant literature, to indicate the most significant tests and experiences.—J. P.

The Practical Aspect of Industrial Exhaust Ventilation. A. C. Mann. (Journal of the Institution of Heating and Ventilating Engineers, 1951, vol. 19, July, pp. 169–190). The author has outlined the design of hoods, and the average velocities for successfully conveying various materials are given. General ventilation design, materials for the construction of ducts, and types of separator are surveyed, and the importance of making and recording test figures is emphasized.—T. E. D.

New Calibration Method for Testing Sieves. (National Bureau of Standards News Bulletin : Industrial Diamond Review, 1951, vol. 11, June, p. 137). A method employing calibrated glass spheres of graduated size has been developed by V. R. Deitz and F. G. Carpenter of the National Bureau of Standards.—T. E. D.

Fire Tests of Steel Columns Protected with Siliceous Aggregate Concrete. N. D. Mitchell. (United States Department of Commerce, May, 1951, Building Materials and Structures Report 124).

Nuclear Radiation and Its Physico-Metallurgical Action. J. B. de Nardo. (Tecnica e Industria, 1951, vol. 29, Apr., pp. 284–286). [In Spanish]. A general explanation is given of the principles involved in chain reactors. General conclusions from published data on the effect of radiation are : (1) The effect of the intensity of radiation is a function of the heat-treatment before irradiation ; (2) mechanical, and sometimes electrical, resistance is increased ; (3) the softer the original alloys, the greater is the effect of radiation on hardness ; (4) radiation effects appear to be permanent (no changes in metals after six months) ; (5) all the changes confirmed appear to be a function of the energy of the neutron, but are not proportional to the period of radiation ; (6) the maximum hardness obtained by radiation does not exceed that obtainable by heat-treatment ; and (7) a 30-sec. immersion in 'adequate

salt baths ' eliminates all changes in hardness and resistivity caused by radiation.—R. S.

The Activities of the Spanish Iron and Steel Institute. (Instituto del Hierro y del Acero, 1950, vol. 3, Oct.–Dec., pp. 296–301). [In Spanish]. This is a brief note on papers presented and the committee meetings during the last quarter of 1950.—R. S.

Metalworking Research Reaches All-Time High. R. A. Lubker. (Iron Age, 1950, vol. 166, Dec. 21, pp. 74–77). A brief description is given of the facilities and equipment available at the Armour Research Foundation of the Illinois Institute of Technology. Work at present is being carried out on 25 projects varying from metal flow in sand to quality control.—A. M. F.

BOOK NOTICES

INSTITUTE OF PHYSICS. "*Some Aspects of Fluid Flow.*" Being the papers presented at a Conference on 25th to 28th Oct., 1950. 8vo, pp. viii + 292. Illustrated. London, 1951 : Edward Arnold and Co. (Price 50*s.*)

This volume consists of the papers presented at a conference organized by the Institute of Physics, together with the reports of the conference discussion groups. The papers are grouped under four main headings : Industrial Problems ; Fundamental Problems ; Techniques ; and Application of Present Knowledge and Techniques : a total of 15 papers being presented. A significant feature of the field covered is the almost complete absence of what might be called ' aircraft aerodynamics,' apart from a paper by Professor A. D. Young entitled " Boundary Layers and Skin Friction in a Compressible Fluid Flowing at High Speeds." The aim has clearly been to bring to light, survey, and discuss the application of a physical approach to industrial problems involving fluid flow. As is remarked in the concluding summary by M. W. Thring " . . . the introduction of physics to the study of fluid flow in various systems is producing a ' fluid flow physics,' just as the introduction of physics to metallurgy has produced ' metal physics.' "

The first group of papers consists of four survey papers, concerned with turbulent mixing (M. P. Newby and M. W. Thring), the combined flow of fluids and solids (R. L. Brown), the pattern of fluid flow (W. A. Simmonds), and the hydromechanics of fluid flow (L. E. Prosser and R. C. Worster). These papers serve as an introduction, demonstrating the extent of the field involved, the empirical methods by which progress has been made in design and development (the open-hearth furnace being a good example), and the difficulty of applying fundamental knowledge to industrial problems. The bibliography in the paper by R. L. Brown is particularly extensive. The third paper, on flow patterns, might more reasonably have been included in the Techniques Section, as a large part of it gives an excellent survey of methods of visualizing flow patterns. Indeed, it is difficult to think of any fluid flow problem in which a knowledge of the flow pattern in the system under consideration is not desirable. It is noticeable in these first four papers that there is a bias on the part of the authors in their material towards the industry with which they are associated.

In the next group of papers, the first, " Problems in the Atomisation of Liquids," by H. L. Green, gives a review of experimental and theoretical work on atomization. Here again the emphasis is on the abundance of literature on the subject, and on the lack of a general theory to put the available information into some sort of order. Professor Young's paper, already mentioned, stands quite apart from the rest, but it is likely that industry will be finding more and more information applicable to their own problems in the very extensive literature of aerodynamics. There are three papers dealing with closely associated subjects ; " The Effect of Concentration on the Settling of Suspensions and Flow through Porous Media " by P. G. W. Hawkesley ; " Fluid Flow through Beds of Granular Material " by H. E. Rose ; and " The Laws of Motion of Particles in Fluid and Their Application to the Resistance of Beds of Solids to the Passage of Fluid " by R. A. Mott. As an illustration of the difficulties awaiting a newcomer to this subject, the methods of computation in the last two papers are different, necessitating a certain amount of preliminary work before results can be compared.

H. E. Dall, in his paper entitled " Some Aspects of Fluid Flow in Orifices, Nozzles and Venturi Tubes," discusses the well-established technique of flow measurement in closed channels by the pressure difference method, and gives a statement of the present state of knowledge on this subject.

Next follow two papers concerned solely with steelmaking. The first, " Techniques for the Study of Fluid Flow " by J. H. Chesters, I. M. D. Halliday, and R. S. Howes, deals only with the open-hearth furnace and simple geometrical shapes related to it. It might, therefore, be more accurately entitled " Flow Patterns in the Open-Hearth Furnace." It is valuable in showing the amount of information which can be obtained by the use of comparatively simple model methods and techniques. But in turn it demonstrates the lack of fundamental knowledge available by the deplorably crude bases of similarity in models. The second paper " Fluid Flow in Relation to the Manufacture of Steel " by M. P. Newby discusses many aspects of iron and steel making in which fluid flow is an important factor. In the last paper of this group R. Mayorcas and K. P. Perry describe the development of a technique for measuring mixing patterns in hot flow systems, using radar as a tracer. A particular application of the technique was in the investigation of open-hearth furnace flames. The method has not, apparently, been applied to an industrial system, and the highest temperature worked at in the laboratory was only 100° C. In the final group of three papers, the first " Theory and Design of Simple Ejectors " by R. A. Smith, demonstrates that a theoretical approach may be applied to the design of certain types of ejector. The second paper, by R. A. Mott, has been mentioned above. The concluding paper of the group is by J. F. C. Conn and is entitled " Turbulence Excitation in Ship Models " ; it describes measurements of of ship hull resistance when a trip wire was fitted near the bow. In both the reports of the discussion groups and the concluding summary by M. W. Thring, the important point which emerges is the awakening of industry to a new subject, " Fluid Flow Physics." We are clearly only on the threshold of the subject and the need for a firm foundation of theoretical knowledge is very apparent. This book, however, helps in clearing the ground for such a foundation rather than supplying it, nevertheless it will form a useful source of general information to anyone interested in fluid flow problems in industry.—J. A. LEYS

"*Mellor's Modern Inorganic Chemistry.*" Revised and edited by G. D. Parkes. 8vo, pp. xxi + 967. London, 1951, Longmans, Green and Co. (Price 25*s.*)

This book is primarily intended for students preparing for their intermediate and pass B.Sc. degree examinations. As such, its worth has long been recognized, and this revised edition is assured of a warm welcome by all colleges and schools.

The text of this new edition has been reset, and advantage has been taken to revise the text, in order to bring the subject matter up to date. The basic arrangement of the 1939 edition has however been maintained. The main changes are that : (1) A new chapters entitled " Metals," has been added, which serves as an introduction to the more detailed consideration given to the metals in subsequent chapters. Sections of this chapter are devoted to the occurrence and preliminary treatment of the ores, the extraction of metals from their ores, the properties of the metals, and a brief account of the oxides and important salts of the common metals. A useful summary is therefore available to the student. (2) A brief account of the methods leading to the release of atomic energy by nuclear fission has been added to the chapter on radioactivity and the radio elements. (3) The chapters on inert gases and the atmosphere have been combined in order to give a more logical treatment of all the gases of the atmosphere.

The diagrams illustrating the book are commendably clear, though in some cases they have been over-simplified and a few photographs illustrating industrial processes would have provided a useful amplification of the text. Incidentally, the text referring to Fig. 35.5 (the iron–

carbon system), refers to letters J and N, which are however not marked on the figure.

The book does present the whole field of inorganic chemistry in an extremely readable manner, and so should hold the attention of the reader and the student.

J. E. WORTHINGTON

MONYPENNY, J. H. G. "*Stainless Iron and Steel.*" Volume I. "*Stainless Steels in Industry.*" Third edition revised. 8vo. pp. xii + 524. Illustrated. London, 1951 : Chapman and Hall, Ltd. (Price 45*s.*)

The first edition of Mr. Monypenny's "Stainless Iron and Steel" which was published in 1926, was and still is a book worthy of a place in any technical library, but this, the 3rd edition, far surpasses the first two editions. The clarity of expression and excellent arrangement which were such outstanding features of the first edition could not, of course, be improved upon, but in this present edition so many more facts are presented that it will undoubtedly remain a standard work of reference for many years to come, and be as valuable to the manufacturer of stainless steels as to the fabricator and user.

The first edition consisted of 293 pages and the second edition of 561 pages. This 3rd edition consists of 501 pages but discusses the subject only from the point of view of the industrial user of stainless steels, and a second volume to appear later will deal with microstructure and constitution.

In the first chapter the composition, general characteristics and mechanical properties of the stainless steels in commercial use are described under three headings: Hardenable Stainless Steels, Ferritic Stainless Steels, and Non-Hardenable Austenitic Stainless Steels. This chapter is particularly comprehensive and details the analysis, heat-treatment, and physical properties, not only of alloys used at low temperatures but also the pertinent properties of materials used for heat-resisting purposes.

The author's comments upon sulphur and phosphorus in the hardenable stainless steels are particularly interesting. He states that there is not a particle of evidence to show that stainless steel with less than 0·03% phosphorus is in any way superior to steel containing 0·05% of that element, and that the rejection of a cast of such steel for no other reason than that its phosphorus content was 0·04% or 0·05% instead of not more than 0·03% would be merely a waste of good material. Small amounts of phosphorus are dissolved in stainless steel in much the same way as sugar dissolves in water, but sulphur behaves more like the sand which dishonest grocers have been alleged in times gone by to mix with sugar. Sulphur exists in stainless steel as small non-metallic particles, probably chromium sulphide, which are merely mixed with the steel and can be easily seen when a polished sample is examined microscopically. The presence of a relatively high content of such non-metallic particles makes it difficult, if not impossible, to obtain a highly polished surface on the steel. It is pointed out that the addition of appreciable amounts of sulphur or of selenium to stainless steel improves the machinability but that the corrosion resistance may be reduced to some extent, and that the use of free-machining stainless steel may be inadvisable, particularly where freedom from pitting is desired. Reference is also made to the comparatively little known and little used Digby Cyptric stainless steels containing 10 to 30% of chromium together with 5 to 25% of copper and to the heat-resisting properties of the 12 to 14% of chromium steels, particularly when the silicon content is high as in the Silchrome steels.

In the section dealing with ferritic stainless steel, the author considers the properties of those containing from approximately 16% up to 30% of chromium.

He mentions that nitrogen may be easily introduced into high-chromium iron by using ferrochrome specially prepared so as to contain the necessary amount of nitrogen. If the amount of nitrogen added is restricted to not more than one-hundredth of the chromium content, impact values are increased and grain growth is retarded.

Hardenable, austenitic stainless steels are considered in six sections: (*a*) Chromium–nickel austenitic steels containing up to 20% chromium; (*b*) austenitic chromium–nickel steels containing upwards of 20% of chromium. (Due to a typographical error this is marked '*C*'); (*c*) intergranular corrosion in austenitic stainless steels and how it can be avoided; (*d*) austenitic chromium–nickel steels containing other alloying elements; (*e*) austenitic chromium–manganese steels; and (*f*) precipitation-hardening austenitic 18/8 steels.

Chapter 2 deals with the working and fabricating of stainless steel. It commences with a section devoted to forging, rolling, and other forms of hot working, and the author points out that all these processes are carried out with the same plant and tools and much in the same way as that of carbon and alloy steels, but that in general, greater care is necessary at all stages, particularly during the early stages of working the ingot. It is in this section that the author deals at some length with a subject which is not often mentioned in connection with stainless steels, namely, riveting operations and other processes used by boiler makers in the construction of plant. The second section deals with heat-treatment in general, and the third with surface hardening. The author points out that nitriding can be applied to most forms of stainless steel, and that under properly controlled conditions, it produces intensely hard skins. At the present time the most important application of nitriding to steels of the stainless family is in hardening parts of the surfaces of aero-engine valves and the linings of aero-engine cylinders. The fourth section deals with descaling. Carbon steel has been descaled by immersion in a suitable acid for many years, but such descaling was almost invariably an intermediate process; the author mentions that conditions are generally different with stainless steel, and although it is also descaled at an intermediate stage for various reasons, descaling is frequently used as a final operation in producing a saleable article. The next two sections (*e*) and (*f*) are devoted to the cold working and machining of stainless steels, and then comes an exceeding important section dealing with welding. This is considered under seven headings, namely: Oxy-Acetylene Welding, Atomic Hydrogen Welding, Metallic Arc Welding, Carbon Arc Welding, Electric Resistance Welding, Heat-Treatment after Welding, and Stress-Relieving of Welded Vessels. The chapter concludes with a short section on soldering and brazing.

Chapter 3, "How Stainless Steels Resist Corrosion," deals briefly with the 'passive film' theory and then follows an enormous amount of detailed information about the behaviour of stainless steels with a number of typical corrosive media. The final section, which considers the combined effects of corrosion and stress, is very interesting, and the author deals with every aspect of the subject. He particularly refers to the difficulties resulting from the need for limiting cyclic stresses in order to obviate corrosion fatigue in aeronautical construction where high stresses are frequently necessary if undue weight is to be avoided. He points out how urgent is the need for data regarding the resistance of various stainless steels through corrosion fatigue in the presence of different corrosive media, and suggests that it is a subject to which professors of engineering, who have suitable fatigue testing equipment, might well direct the attention of their research students as there is urgent need for much further investigation.

Chapter 4 deals with the behaviour at high temperatures of heat-resisting steels, the earlier part of the chapter being devoted to a consideration of oxidation tests and the like, and the latter part to the physical properties when subject to stress at a high temperature for a considerable length of time. The author points out that aluminium is even more effective than silicon in increasing the resistance of chromium steels to oxidation, and that when added by itself to steel in amounts of 12% and upwards, it gives very good protection against oxidation.

In the final chapter, the author deals with the selection of stainless steels for industrial purposes under four headings, namely: (*a*) Domestic, Hospital, Decorative, and Architectural Purposes; (*b*) Power Plant, Aeronautical, Automobile, Railway, and General Engineering Purposes; (*c*) Chemical Engineering Purposes; and (*d*) Heat-Resisting Purposes.

In conclusion one cannot do better than to quote from Professor F. C. Thompson's foreword ". . . his (Mr. Monypenny's) contribution to our knowledge of the metallography and properties of the high-chromium steels is probably the outstanding contribution made from this country in the whole field of ferrous metallurgy in the last twenty-five years."—J. FERDINAND KAYSER

SALMON, W. H. and E. N. SIMONS. "*Foundry Practice.*" 8vo, pp. xiii + 384. Illustrated. London, 1951: Sir Isaac Pitman and Sons, Ltd. (Price 30*s.*)

This book should be welcomed by foundry students. It is wide in its scope and covers the essentials of technical drawing, casting and pattern design, sand moulding and core practice, a good introduction to the metallurgy of practical metal melting and preparation, and the heat-treatment of castings. Ferrous and non-ferrous practice is considered. The book is concise and to the point, the object being to avoid confusing students with matter not bearing closely upon the course for the intermediate examination in foundry practice set by the City and Guilds Institute. The syllabus for this course is adequately treated. The authors have evidently been at considerable pains to make their descriptions of plant and techniques clearly understandable to the beginner, and in doing so have shown an intimate knowledge of their subject. The trial questions and specimen answers, and advice on preparing for the examinations should prove most helpful. Characteristic of the book is the thoughtful tinge of humour about the toy engine 'on the drawing board' in the first few pages and which, no doubt, is a good psychological introduction to a book destined for students with a bent for the practical.

The book is not without its points for criticism, although on the whole they are minor ones. It might have been useful to have discussed the rather restricted application of the homogenizing treatment to steel castings, as well as the application of this treatment to non-ferrous metals. The value of annealing is not questioned, merely the use of an inadequate term. Two or three of the photomicrographs are rather disappointing. It is easy for the experienced micrographer to see what inexperienced observers do not, even in those micrographs that are relatively poor, hence there is a particular need for good resolution and general definition for students. Some metallurgical definitions could be more accurate without being too theoretical, *e.g.*, that of austenite (p. 288). The authors are, however, on dangerous ground when using the heat of formation of an oxide (p. 255) as a measure of stability for comparing reducibilities of oxides. The heat of formation is not a reliable guide. The values quoted in the text are for 298° K. and are no proof of their value above that temperature. To consider an ordered arrangement of such oxides it would be necessary to know the individual temperature/standard-free-energy relationships or oxygen potentials for each oxide. On such a basis it would be seen that the order of the oxides in the text would be different at higher temperatures in some cases. What is said about 'affinity for oxygen' should be changed in any subsequent edition. Similarly, more care should be taken in discussing oxidizing, reducing, and neutral atmospheres (p. 228). A plea for simplicity for the sake of students not trained in science should not have deterred the authors from giving an accurate description. Before leaving the present point, the place of titanium should be mentioned (table 35, p. 225). This metal presents a difficult melting problem, and the oxide which is most troublesome to reduce is TiO not TiO_2, having—for what it is worth—a heat of formation of −124 kg.cal., and even metals like calcium are likely to be of little use for the reduction of this oxide, judging by recent researches on the subject. However, the reviewer feels that it would be best to keep thermodynamical concepts out of a book which is essentially practical in its bearing.

Apart from these points, the book is most commendable and is very well illustrated.—E. J. D. SMITH.

[In the list of periodicals included in this book, it is stated on pages 372 and 373 that the *Journal of The Iron and Steel Institute* is published in two volumes annually, and the *Bulletin* monthly. This is incorrect, as the *Journal* has been issued monthly since January 1947 and the *Bulletin* ceased publication in December 1946.—EDITOR].

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Annual Statistical Report*, 1950. 8vo, pp. 100. New York, 1951: The Institute.

BIANCHI, L. W. P., AND E. M. ZWEEKHORST. "*Metalen en Metaalbewerking*," Part I—"*Metalen legeringen, Metaalonderzoek.*" Pp. 224 with 198 illustrations. Part II—"*Bewerken van Metalen in plastische toestand, walsen, smeden, persen en trekken.*" Pp. 180, with 132 illustrations. Rotterdam, 1951: Nijgh and Van Ditman N.V. (Price Part I, 11.75 florins; Part II, 15.50 florins)

BOSTON, O. W. "*Metal Processing.*" Second edition. 8vo, pp. 763. Illustrated. New York, 1951: John Wiley and Sons, Inc; London: Chapman and Hall, Ltd. (Price $7.50)

BRITISH ELECTRICAL AND ALLIED MANUFACTURERS' ASSOCIATION. "*Beama Guide to British Electrodes Covering Arc Welding Electrodes for Welding Mild Steel.*" 8vo, pp. 45. London, 1951: The Association. (Price 2*s.*)

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1950. Part I. "*United Kingdom Statistics.*" 4to. pp. vii + 121. London, 1951: The Federation. (Price 7*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1760: 1951. "*Carbon Steel Castings for Surface Hardening.*" 8vo, pp. 9. London: The Institution. (Price 2*s.*)

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH TECHNICAL INFORMATION AND DOCUMENTS UNIT. "*A Bibliographical Survey of the Development and Use of Substitute Materials for Non-Ferrous Metals and Alloy Steels in Germany.*" Report No. RMS-2. 8vo, pp. 46. London, 1951: H.M. Stationery Office. (Price 1*s.* 6*d.*)

DICKINSON, D. "*The Chemical Analysis of Waters, Boiler- and Feed-Waters, Sewage and Effluents.*" (Blackie's Technique Series). Second edition. 8vo, pp. xii + 144. London, 1950: Blackie and Son, Ltd. (Price 6*s.* 6*d.*)

INSTITUTE OF PETROLEUM. "*A Glossary of Petroleum Terms.*" Prepared by the Nomenclature Sub-Committee of the Institute of Petroleum. 8vo, pp. 15. London, 1951: The Institute.

KRÄMER, O. P. "*Die Hartverchromung.*" Pp. 120, with 78 illustrations. Berlin, 1951: Metallverlag G.m.b.H. (Price DM 8.40)

KORTÜM, G., and J. O'M. BOCKRIS. "*Textbook of Electrochemistry.*" Volume 1. Pp. xvi + 351, with 48 illustrations. Amsterdam, 1951, Elsevier Publishing Company; London: Cleaver-Hume Press Ltd. (Price 50*s.*)

MÜLLER, E. A. W. "*Materialprüfung nach dem Magnetpulver Verfahren?*" 8vo, pp. vi + 144. Illustrated. Leipzig, 1951: Akademische Verlagsgesellschaft Geest und Portig K. G. (Price DM 17.–)

NATIONAL ASSOCIATION OF CORROSION ENGINEERS. "*Bibliographic Survey of Corrosion* 1946–1947." Pp. 288. Houston, Tex. 1951: The Association. (Price $9)

RABALD, E. "*Corrosion Guide.*" Amsterdam: Elsevier Publishing Co., Inc. (Price 45.50 florins)

SACHS, G. "*Principles and Methods of Sheet-Metal Fabricating.*" 8vo, pp. 526. Illustrated. New York, 1951: Reinhold Publishing Corp. (Price $10)

SCHIMPKE, P. "*Kurzgefasste Werkstoffkunde.*" 8vo, pp. viii + 171. Illustrated. Leipzig, 1951: S. Hirzel Verlag. (Price DM 4.50)

SCHÖNERT, K. UND R. ESCHELBACH. "*Praktische Metallprüfung.*" Band 1—"*Die mechanisch-technologischen Prüfverfahren und ihre Anwendung.*" Pp. 274 with 206 illustrations. Brunswick, 1950: Georg Westermann Verlag. (Price DM 28.–)

SISCO, F. T. "*Das Elektrostahlverfahren—Ofenbau, Elektrotechnik, Metallurgie und Wirtschaftliches.*" Nach F. T. Sisco "*The Manufacture of Electric Steel.*" 2. deutsche erw. Aufl. von H. Siegel. 8vo, pp. xi + 432. Illustrated. Berlin, Göttingen, Heidelberg, 1951: Springer-Verlag. (Price DM 31.50)

VOGEL, O. "*Handbuch der Metallbeizerei.*" Band 1. "*Nicht-eisenmetalle.*" Neubearbeitet von H. Vogel, K. Kaiser, H. Krause und F. Sierp. 2. Auflage. Pp. xv + 410, with 263 illustrations. Weinheim, 1951: Verlag Chemie. (Price DM 49.20)

ZIMMERMAN, E. W. "*World Resources and Industries.*" Pp. 832. New York, 1951: Harper & Bros.

SIR CHARLES BRUCE-GARDNER, Bt., M.I.Mech.E.

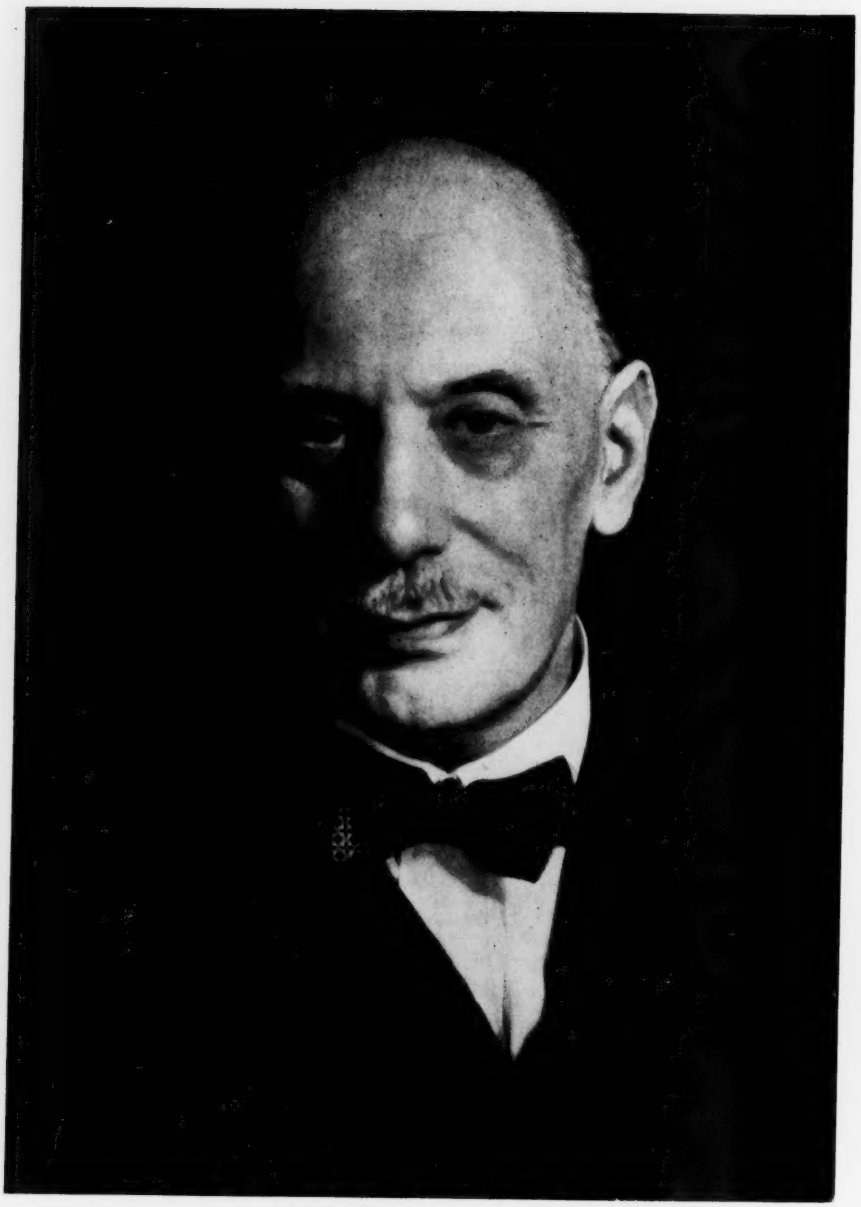
SIR CHARLES BRUCE-GARDNER, Bt., Chairman of John Lysaght Limited, was born in London and educated at St. Dunstan's College and at Battersea Technical College, afterwards serving his mechanical engineering apprenticeship at the Westinghouse Company's works at Trafford Park, Manchester. On completion of his apprenticeship, Sir Charles obtained an appointment with John Summers and Sons, Shotton, as Assistant to the Steelworks Manager and Rolling Mill Manager, afterwards succeeding to the position. Later, he became Assistant Works Manager and then Works Manager, and was elected to the Board in 1913.

From 1929 to 1930 Sir Charles was Chairman of the Iron and Steel Industrial Research Council. At the same time, he became a Member of the Advisory Committee of the Department of Overseas Trade. In 1930 his activities were broadened to cover a much wider front of industry and commerce. In that year he joined the Bank of England to become Industrial Adviser to the Governors, and was also appointed Managing Director of the Bankers' Industrial Development Company, Limited, and of The Securities Management Trust, Limited, the Bank of England Company. Both companies, working in collaboration, were instrumental in providing finance for some of the steel industry's larger developments. In 1936, and in 1937, he was Chairman of the Iron and Steel Exchange.

In December, 1937, at the request of the Government, Sir Charles left the Bank of England to assist in the Government's air re-armament programme, and was appointed Independent Chairman of the Society of British Aircraft Constructors. During the Second World War he served on many Government Committees and in a number of executive positions.

Towards the end of the war Sir Charles was appointed by the President of the Board of Trade to the position of Chief Executive for Industrial Reconversion, to deal with the industrial problems arising from the change-over from war to peace-time conditions. At the completion of this work he returned to the steel industry and is now a Director of a number of steel companies.

Sir Charles is a Member of Council and of the Executive Committee of the British Iron and Steel Federation. He joined The Iron and Steel Institute in 1910 and was elected a Member of Council in 1950.



Lotte Meitner-Graf

Sir Charles Bruce-Gardner, Bt.
Member of Council

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Weldability and Mechanical Properties of a Series of Low-Alloy Steels

By J. G. Ball, B.Sc., A.I.M., and C. L. M. Cottrell, M.Sc.

SYNOPSIS

An investigation of the weldability and mechanical properties of a series of 27 experimental low-alloy manganese–nickel–chromium–molybdenum steels of constant carbon and molybdenum contents is reported; four nickel-free (< 0·1%) steels and four containing copper were also tested. All the steels were made in small high-frequency induction-furnace melts, the weldabilities in the normalized condition being determined by a modification of the Reeve fillet-weld cracking test. The mild-steel metal-arc electrodes used had a rutile base coating. Diagrams indicating the effect of steel composition on weldability were constructed, and were compared with others indicating the mechanical strength of the steels in both the normalized and tempered conditions, these comparisons leading to a range of compositions giving the best combination of weldability and mechanical strength. The microstructure of the steels in the normalized condition has been related to their weldability, and the effect of tempering temperature after normalizing on the mechanical properties and microstructure of one of the steels has been investigated; evidence to support a significant relationship observed has been obtained from a number of the other steels of the series.

INTRODUCTION

THE weldability of an alloy steel can be expressed in terms of the liability to crack formation in the hardened zone adjacent to the weld under a given set of conditions. Since alloy steels are used because of their high strength it is important that any research into their weldability should include an adequate investigation of the mechanical properties. As very little was known about the effect of various combinations of the alloying elements in low-alloy steels it was decided to investigate a series of such steels of varying alloy content.

A systematic study of the effect of variations of the six common alloying elements on the properties of a multiple-alloy steel would entail investigation of a series of more than 700 steels, but the number was reduced subsequent to the following considerations: Since the adverse effect of carbon on weldability is well known, it was decided to maintain the carbon content constant at a low value throughout the series, and as large amounts of molybdenum would be undesirable for economic reasons it was decided to maintain the molybdenum content also constant at a low value, though some addition of molybdenum was considered to be desirable for the maintenance of high yield stress without adversely affecting weldability. Copper was also thought to improve the yield stress without affecting the weldability, and since this is one of the less common alloying elements it was decided to study the effect of copper additions in only a few of the steels.

This restriction of the variable elements left a main series of 27 steels with three levels of manganese, nickel, and chromium content in all combinations. Four steels containing copper were also included in the initial investigation, and at a later date it was decided to include some steels without added nickel, since the low-nickel region of the series appeared to be showing interesting properties.

Review of Previous Work

Very little work on the effect of systematic variations of alloy content on the weldability of alloy steels has been published, the most complete investigation on these lines being that reported by Sims and Banta,[1] who studied a large number of experimental steels by means of an underbead cracking test. A carbon–manganese steel was used as a basis, various amounts of each alloying element being added one at a time; the mutual effect of various combinations of alloying elements was not studied. The effects of the various

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alloy additions which were observed were as follows :

Element Added	Effect on Weldability	Effect on Yield Stress
Carbon, manganese	Bad	Marked improvement
Molybdenum, vanadium	Slight reduction	Marked improvement
Silicon, titanium	Slight reduction	No effect
Chromium	Variable	No effect

Weldability and mechanical tests have been carried out by Dearden and O'Neill,[2] on a number of alloy steels, the effect of variations in manganese, nickel, chromium, and molybdenum contents in particular being studied, and a theory of carbon equivalents was proposed. These carbon equivalents indicate the amount of any given element necessary for incorporation in an alloy steel to give the same effect as a unit addition of carbon, and were given for the yield stress and tensile strength and also for the hardenability in the heat-affected zones of arc welds. According to Dearden and O'Neill, 350 D.P.H. can be taken as a safe upper limit of hardness in the heat-affected zone for arc welds made with a normal electrode, though in some instances this value may be increased to 400 D.P.H., and they suggest that when an alloy steel is to be welded its heat-affected-zone hardenability should be calculated from its chemical composition by using carbon equivalents. The minimum weld-fillet size necessary to prevent the heat-affected-zone hardening to a value greater than 350 D.P.H. can then be deduced.

Weldability tests on a number of commercial alloy steels have also been described by Reeve,[3] and safe upper limits of 400 D.P.H. for maximum and 350 D.P.H. for mean heat-affected-zone hardness, respectively, to prevent hard-zone cracking, have been proposed.

DETERMINATION OF WELDABILITY

In determining the relative weldabilities of a series of experimental alloy steels the following factors have to be considered :

(*a*) The severity of the cooling rate to which the joint is subjected
(*b*) The rigidity of the welded joint
(*c*) Economy of material.

The most severe conditions of factors (*a*) and (*b*) are usually obtained when arc welding is carried out on thick sections, but factor (*c*) need only be recognized when the amount of material available is small. A weldability test which fulfils conditions satisfying these factors is the Reeve fillet-weld cracking test, the rigidity of which is as severe as is likely to be found

Table I

CAST ANALYSES OF EXPERIMENTAL STEELS

Steel	C, %	Si, %	S, %	P, %	Mn, %	Ni, %	Cr, %	Mo, %	Cu, %
1	0·14	0·18	0·029	0·036	0·73	0·48	0·24	0·22	...
2	0·16	0·18	0·025	0·038	1·13	0·50	0·25	0·24	...
3	0·15	0·21	0·030	0·044	1·52	0·51	0·25	0·24	...
4	0·15	0·17	0·029	0·035	0·78	1·01	0·25	0·22	...
5	0·16	0·22	0·025	0·035	1·15	1·00	0·25	0·22	...
6	0·13	0·20	0·025	0·037	1·53	1·01	0·25	0·22	...
7	0·16	0·17	0·027	0·037	0·74	1·51	0·24	0·22	...
8	0·16	0·21	0·026	0·036	1·11	1·55	0·24	0·22	...
9	0·145	0·25	0·031	0·037	1·63	1·50	0·17	0·24	...
10	0·15	0·23	0·027	0·032	0·79	0·50	0·68	0·22	...
11	0·155	0·21	0·034	0·023	1·22	0·55	0·65	0·26	...
12	0·16	0·19	0·042	0·021	1·58	0·57	0·66	0·245	...
13	0·145	0·15	0·028	0·024	0·71	1·06	0·60	0·26	...
14	0·17	0·22	0·028	0·024	1·00	1·05	0·645	0·265	...
15	0·15	0·21	0·043	0·021	1·71	1·07	0·66	0·24	...
16	0·155	0·15	0·024	0·024	0·64	1·57	0·56	0·245	...
17	0·155	0·20	0·027	0·025	1·26	1·52	0·66	0·25	...
18	0·16	0·18	0·043	0·024	1·70	1·53	0·62	0·23	...
19	0·155	0·17	0·032	0·024	0·74	0·57	1·03	0·245	...
20	0·135	0·18	0·043	0·021	1·00	0·51	1·00	0·235	...
21	0·135	0·18	0·043	0·024	1·64	0·55	0·89	0·25	...
22	0·13	0·18	0·035	0·031	0·80	1·03	1·01	0·25	...
23	0·13	0·18	0·036	0·034	1·25	1·02	0·99	0·25	...
24	0·15	0·21	0·035	0·034	1·70	1·03	1·03	0·25	...
25	0·17	0·16	0·032	0·029	0·79	1·59	1·01	0·25	...
26	0·15	0·21	0·032	0·029	1·26	1·55	1·00	0·26	...
27	0·13	0·23	0·033	0·034	1·64	1·50	1·03	0·23	...
28	0·13	0·19	0·035	0·035	0·86	0·94	0·23	0·21	0·94
29	0·14	0·21	0·035	0·032	0·83	1·44	0·22	0·25	1·12
30	0·15	0·20	0·033	0·026	0·87	1·02	0·58	0·25	1·13
31	0·14	0·19	0·033	0·028	0·84	1·49	0·63	0·25	1·12
33	0·13	0·19	0·023	0·040	1·52	0·07	0·17	0·26	...
34	0·16	0·21	0·022	0·040	0·83	0·07	0·52	0·25	...
35	0·14	0·18	0·027	0·039	1·23	0·09	0·56	0·25	...
36	0·13	0·17	0·021	0·041	1·42	0·09	0·56	0·25	...

in any structural joint in practice, and the massive base-plate used provides an adequate heat sink comparable to the cooling conditions with very thick plates; for these reasons it was decided to use the Reeve test in the investigations described in the present paper.

The test has been described by Reeve,[3] and the type of modification used in the present study, described by Dearden and O'Neill,[2] enables two test welds to be made instead of one, giving considerable economy of material. The test welds in the modified equipment were 5 in. long compared with 6 in. for the standard Reeve test and the modification employed by Dearden and O'Neill. To obtain a complete weldability test from the 18-lb. high-frequency melts used it was necessary to reduce the top-plate width (weld length) to 5 in.

Only one type of electrode was used in the initial series of tests, with the object of conserving material; this was of the general-purpose mild-steel type with a high titania content in its coating, and represented one of the most generally used types available at the time.

Material Used

The experimental steels were produced in 18-lb. high-frequency induction-furnace melts, using Lowmoor iron as a base for the furnace charge. The production of a melt of one of the steels has been fully described in a previous publication.[4]

On solidification of each ingot the mould was immediately removed and the ingot cooled in sand in order to prevent hairline-crack formation. A larger piece from the lower part and a smaller piece from the upper part of the ingot were then forged to give plates slightly over $\frac{1}{2}$ in. thick, the Reeve-test top plates being obtained from the upper part and the bottom plates from the lower part of the ingots. The plates were then normalized and rough surface-ground. The analyses for the series of steels, obtained from drillings taken from the ingots before forging, are given in Table I.

The electrodes used were BEAMA–IOW E217, 10 S.W.G. and 6 S.W.G. being employed for the test welds and 8 S.W.G. for the anchor welds. The test-weld electrodes were all taken from one batch in order to obtain uniform test conditions throughout the series.

EXPERIMENTAL PROCEDURE

Plate and Electrode Preparation

The plates were first drilled with $\frac{15}{16}$-in. diameter holes for the clamping bolts, to suit the Reeve test assembly, and were then fine surface-ground. The top plate was 5 in. sq. by $\frac{1}{2}$ in. thick, and the bottom plate was 6 × 10–12 × $\frac{1}{2}$ in. With steel 10 the plates were inadvertently forged to under $\frac{1}{2}$ in. thick and the final thickness was approximately $\frac{3}{8}$ in. All contact surfaces were fine surface-ground and the edges of the top plates were machined.

In order to limit the available hydrogen in the arc atmospheres, the moisture content of the test-weld electrodes was maintained at a constant level by heating the electrodes in an air-circulating oven at 110° C. for 2 hr., the electrodes being used immediately after removal from the oven. As the electrode coating was known to be hygroscopic, in no instance was the time elapsing between removal of the electrode from the oven and its use permitted to exceed 10 min.

Details of Weldability Tests

The test plates were tightly bolted, using eight $\frac{7}{8}$-in. diameter mild-steel bolts, to a 16 × 12 × $2\frac{1}{4}$-in. thick mild-steel base-plate which could be tilted at an angle of up to 45° to the horizontal. Anchor welds consisting of three runs made in the horizontal position with a welding current of 170 amp. were made on two opposite sides of the top plate, using 8 S.W.G. electrodes; the plates were then allowed to cool to room temperature, the clamping bolts tested, and any slackness taken up.

The test assembly was tilted to an angle of 45° to the horizontal in one direction for the small fillet weld made with the 10 S.W.G. electrode in one run, then tilted in the opposite direction for the large fillet weld made with the 6 S.W.G. electrode in one run, in order that the test welds should be made in the downhand position. An attempt was made to obtain weld sizes of 0·2-in. leg length for the small and 0·3-in. leg length for the large fillets, and in order to repeat these weld sizes with all the tests a given length of electrode was marked for each test weld.

Since the presence of hard-zone cracks was to be used as a criterion of weldability it was necessary to ensure that adequate time was allowed for these cracks to form. Leder[5] has shown that these cracks are liable to form some hours after welding, and Reeve[6] has observed the propagation of a hard-zone crack actually taking place at room temperature under the microscope. The test assembly was thus left bolted together for a minimum of 18 hr. before removal from the jig, and in no instance was any metallurgical examination carried out on sections cut from the tests before one week had elapsed after making the test weld.

Typical welding conditions for both the small and large fillet test welds, the welding current being measured by means of a moving iron ammeter with a current transformer and the voltage by a moving coil voltmeter, were (*a*) electrode size 10 S.W.G., open-circuit voltage 80, arc voltage 19, welding current 125 amp., electrode length used 9·25 in., fillet leg length 0·20 in., and (*b*) electrode size 6 S.W.G., open-

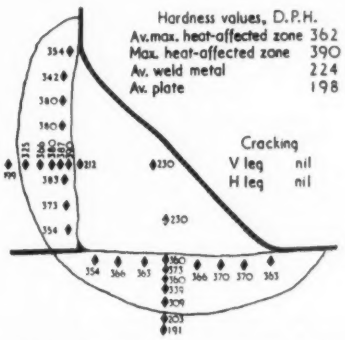

Fig. 1—Hardness traverses indicating relative positions of impressions. Values given are for steel 20

circuit voltage 80, arc voltage 18, welding current 210 amp., electrode length used 8·25 in., fillet leg length 0·30 in.

Sectioning and Examination of Test Welds

The test welds were cut out parallel to the welding direction and sectioned in three places to give specimens approximately $\frac{3}{8}$ in. thick. Three sections were taken from each of the test welds, $1\frac{1}{2}$ in. from the start, at the centre, and $1\frac{1}{2}$ in. from the end of the weld.

All the specimens were polished mechanically and then etched in a solution containing 3% picric acid and 3% hydrochloric acid in alcohol. The microscopical examination for cracks was carried out at a magnification of 400 diameters using a bench microscope. Crack lengths were measured directly on the screen of a projection microscope adjusted to give an accurate magnification of 250 diameters, and were expressed as a percentage of the length of the fillet leg in which they occurred ; this method of expressing severity was satisfactory, as the plane of cracking was nearly always parallel to the fusion line. In cases where a magnification of 2000 diameters was desired for photomicrography the specimens were repolished,

Table II

SUMMARY OF RESULTS

Steel	Alloy Content			0·3% Proof Stress, tons/sq. in.		Small Fillet (10 S.W.G. Electrode)			Large Fillet (6 S.W.G. Electrode)		
	Chromium	Nickel	Manganese	Normalized	Normalized and Tempered	Av. Max. Hardness Heat-Affected Zone, D.P.H.	Av. Plate Hardness, D.P.H.	Cracking V + H Leg, % and Type*	Av. Max. Hardness Heat-Affected Zone, D.P.H.	Av. Plate Hardness, D.P.H.	Cracking V + H Leg, % and Type*
1	Low	Low	Low	21·5	24·0	326	172	Nil	274	175	Nil
2			Medium	26·6	30·0	399	193	17 F	361	194	Nil
3			High	33·1	34·9	419	223	51 C	391	220	28 C
4		Medium	Low	24·9	27·7	376	193	0·3 M	301	183	Nil
5			Medium	28·5	30·0	408	216	47 C	379	216	Nil
6			High	34·8	34·6	408	235	43 C	383	229	25 F
7		High	Low	28·0	30·0	388	203	4 M	343	197	Nil
8			Medium	31·3	34·6	419	220	59 C	386	217	21 F
9			High	..	..	422	250†	50† C	419	250†	50† C
10	Medium	Low	Low	29·2	31·4	380	203	Nil	337	199	Nil
11			Medium	34·0	31·7	410	223	32 F	388	215	5 M
12			High	35·8	38·8	420	262	56 C	406	248	31 F
13		Medium	Low	29·8	33·0	387	187	0·2 M	346	185	Nil
14			Medium	32·8	34·0	402	225	40 C	388	219	14 F
15			High	44·5	38·1	427	311	60 C	410	286	32 F
16		High	Low	31·1	32·0	401	213	8 M	354	208	0·2 M
17			Medium	38·0	36·0	416	258	55 C	399	249	26 F
18			High	45·0	38·7	423‡	299	64 C	412‡	289	37 F
19	High	Low	Low	33·0	31·0	392	190	15 C	351	194	Nil
20			Medium	33·3	35·4	401	196	36 F	362	198	Nil
21			High	42·5	38·7	411	257	55 C	406	274	25 C
22		Medium	Low	32·0	34·7	394	241	22 F	347	228	1 M
23			Medium	38·0	38·1	413	294	71 C	401	288	54 C
24			High	50·0	42·5	433‡	338	69 C	420‡	317	48 F
25		High	Low	38·0	37·5	407	277	45 F	398	275	27 F
26			Medium	50·0	42·0	415‡	304	60 C	415‡	300	57 C
27			High	53·5	43·5	422‡	338	77 C	412‡	320	63 C
28§	Low	Medium	Low	29·0	32·3	381	217	23 F	321	214	0·5 M
29§		High	Low	32·0	33·6	384	221	17 F	372	227	19 F
30§	Medium	Medium	Low	35·8	38·0	402	254	42 F	382	249	37 C
31§		High	Low	38·0	38·3	405	276	57 C	400	267	33 F
33	Low	Zero	High	32·5	36·3	433	246	70 C	387	243	44 F
34	Medium	Zero	Low	23·2	30·0	367	188	3 M	333	180	Nil
35			Medium	33·5	37·2	413	229	34 F	390	225	2 M
36			High	36·0	39·5	424	268	58 C	404	254	35 C

* M denotes micro cracks, F fine cracks, and C coarse cracks
† Approximate value
‡ Values for impressions made approximately 1 mm. from fusion zone
§ Copper-containing steel

Fig. 2—Micro cracks in steel 27 × 250

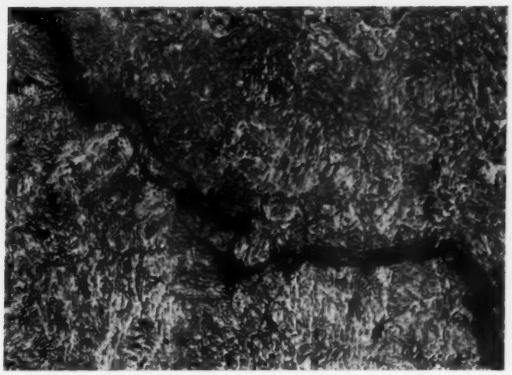

Fig. 3—Fine crack in steel 18 × 250

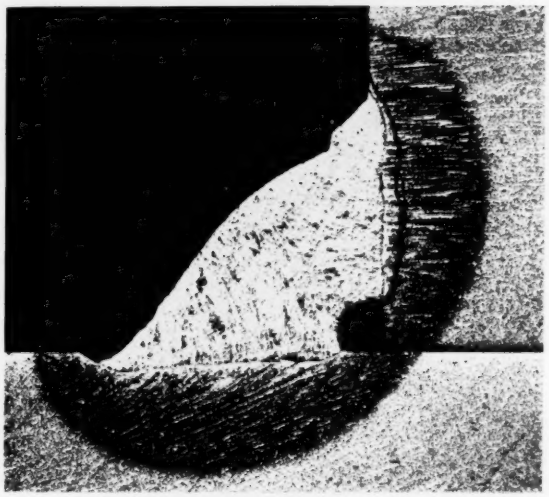

Fig. 4—Coarse crack in steel 18 × 7

Fig. 5— Coarse, fine, and micro cracks in steel 18 × 250

Figs. 2 to 5—Types of cracking in heat-affected zone. All specimens etched in 3% picric acid and 3% hydrochloric acid in alcohol

[*Ball and Cottrell*
[*To face p.* 324

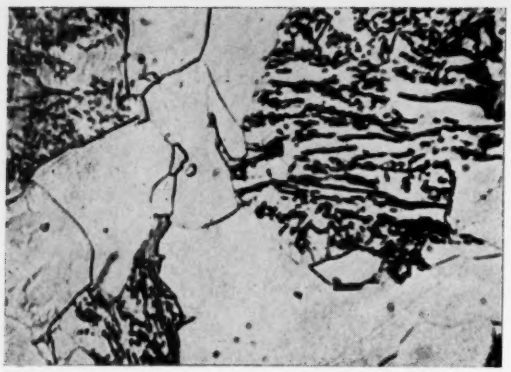

Fig. 6—Steel 2, no cracking. Pearlite in ferrite matrix

Fig. 7—Steel 20, no cracking. Troostite and traces of unresolved martensite in ferrite

Fig. 8—Steel 5, no cracking. Structure as in Fig. 7

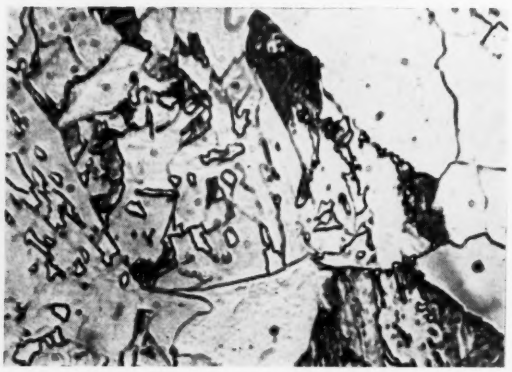

Fig. 9—Steel 28, ½% cracking. Troostite and unresolved martensite in ferrite

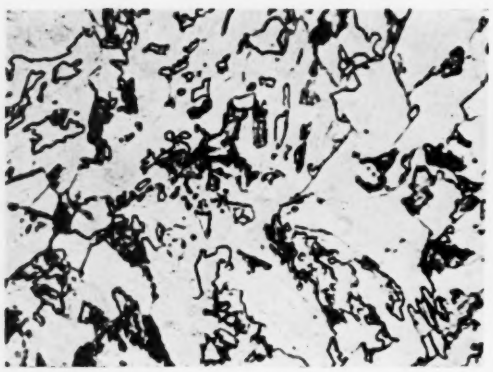

Fig. 10—Steel 22, 1% cracking. Structure as in Fig. 9

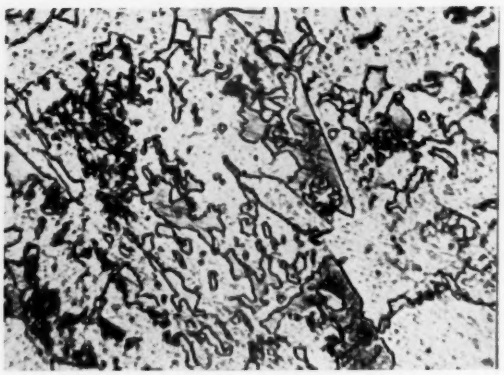

Fig. 11—Steel 11, 5% cracking. Structure as in Fig. 9 with greater proportion of martensite

Figs. 6 to 11—Microstructures of normalized plates. Specimens etched in 2% nital × 2000

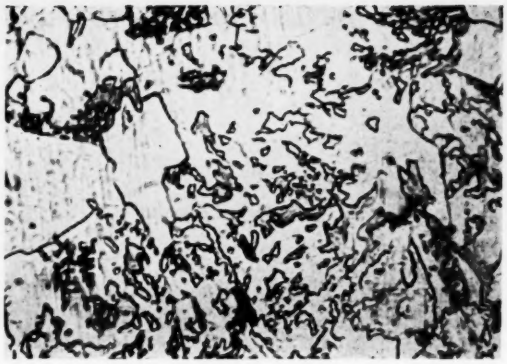

Fig. 12—Steel 14, 14% cracking. Unresolved martensite in ferrite

Fig. 13—Steel 23, 54% cracking. Structure as in Fig. 12

Figs. 12 and 13—Microstructures of normalized plates. Specimens etched in 2% nital × 2000

Fig. 14—Tempered 100°C. Troostite and unresolved martensite in ferrite matrix

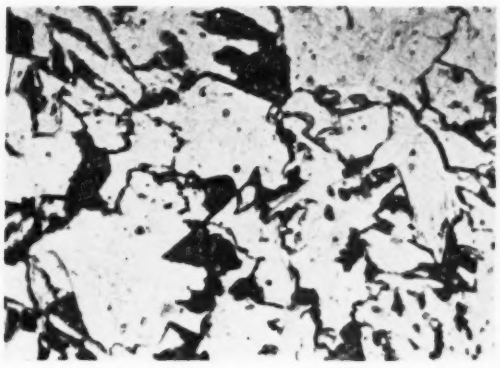

Fig. 15—Tempered 300°C. Martensite decomposing to sorbite

Fig. 16—Tempered 600°C. Sorbite and troostite in ferrite ; martensite decomposed

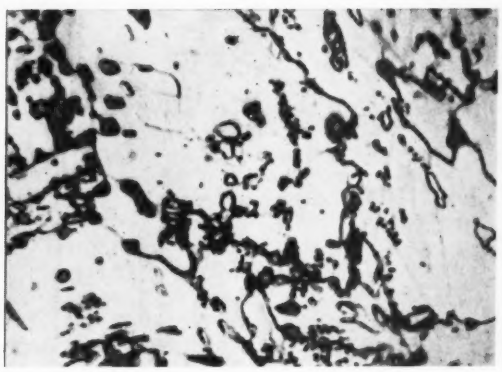

Fig. 17—Tempered 700°C. Spheroidization of carbides

Figs. 14 to 17—Effect of tempering on microstructure of steel 5. Specimens etched in 2% nital × 2000

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lightly etched in 2% nital, and photographed on the projection microscope.

Hardness Exploration

After polishing and etching, hardness tests were made on the centre section of each test weld as shown in Fig. 1. As only a short distance was permissible between indentations owing to the small size of the zone being examined, a 10-kg. load on a diamond-pyramid hardness machine was chosen, indentations being made on a line parallel to the limit of the fusion zone and in the region of maximum hardness, *i.e.*, about ½ mm. from the fusion zone. The term " average maximum hardness " will be used to indicate the average value of these indentations, and " maximum hardness " to indicate the highest single value. The region of maximum hardness was found by means of a line of indentations perpendicular to the fusion line, the hardness traverses given in Fig. 1 indicating the relative positions of the impressions. In a few of the higher-alloy steels the maximum hardness reading was observed further from the fusion zone, and in these instances the indentations were made correspondingly further away from the fusion zone (1 mm.). Where marked variations in the plate structure could be seen microscopically, extra hardness readings were taken in order to obtain a more correct average value of hardness for the unaffected plate material. Three hardness indentations were made on the weld metal and three on the unaffected plate material in each section explored, and the values reported as average plate hardness are the averages of these readings.

EXPERIMENTAL RESULTS

Nature of Observed Cracks

The different types of cracks in the heat-affected zones of the steel have been termed coarse, fine, and micro. Micro cracks (Fig. 2) are defined as those which can be seen only at magnifications greater than 400 diameters in a specimen etched in 2% nital, and are usually of a constant width. Fine cracks (Fig. 3) are defined as those which can be seen in an etched specimen at low magnifications, *i.e.*, up to 10 diameters ; the width of these cracks varies considerably along their length, in some places being little wider than micro-cracks and in other places much larger. Coarse cracks (Fig. 4) are defined as those which have opened out for their whole length, owing to the overall contraction stress developed in the weldability test ; these cracks can be seen visually in specimens in the polished and unetched condition. In Table II, in which the results of all the weldability tests are summarized, the type of cracking given is always that which predominates, because all types can exist together, as indicated in Fig. 5, which shows coarse, fine, and micro cracks side by side in the vertical-leg heat-affected zone of the small fillet weld on steel 18.

It has been observed that hard-zone cracks may be both transcrystalline and intercrystalline in the same steel. This is indicated in Fig. 2, which shows part of the horizontal-leg heat-affected zone of steel 27, where the micro cracks follow grain boundaries in some places and cross grains at others. In no steel of the series was the cracking completely trans-

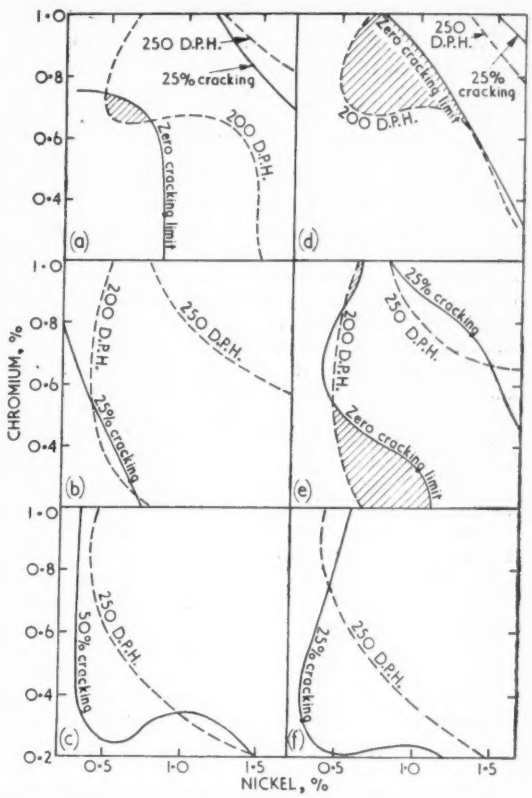

Fig. 18—Plate cracking and hardness diagrams for (*a*) low, (*b*) medium, and (*c*) high manganese in small fillets, and (*d*) low, (*e*) medium, and (*f*) high manganese in large fillets

crystalline or intercrystalline. When all types of cracking are present the micro cracks are usually found nearer to the fusion line, as shown in Fig. 5.

The type of cracking found in all the horizontal-leg heat-affected zones was exclusively micro in character. This can be explained by the fact that the major contraction stress in this leg in the weldability test is a shear stress acting parallel to the cracking plane, which does not tend to open out any such cracks. In the vertical-leg heat-affected zones, however, the predominant type of cracking depends to some extent on the length of cracking present, as is to be expected, since in this instance the major applied stress acts in a direction perpendicular to the cracking plane and tends to widen the cracks.

The major contraction stress is developed on cooling in the Reeve-test top plate. As the top plate is securely anchored to the bottom plate by the side or anchor welds it cannot move bodily with respect to the bottom plate, but when the test weld is made the top plate expands owing to heating near to the weld, and the front, or test-weld, edge moves forward relative to the bottom plate. On subsequent cooling of the joint the front edge of the top plate contracts and stresses the vertical leg of the weld in tension.

Alloy-Content/Plate-Hardness/Cracking Relationship

The relationship between alloy content, plate hardness, and severity of cracking for the main series of manganese–nickel–chromium–molybdenum steels is shown in Fig. 18, the respective diagrams being obtained by taking a constant value for nickel, chromium, or manganese and plotting the values of the other two variable elements as abscissae and ordinates; a curve can then be drawn representing points at which hard-zone cracking just disappears in the Reeve test, and similar curves can also be drawn for other degrees of severity of cracking and for given values of normalized-plate hardness. The values chosen for these diagrams were zero, 25%, and 50% cracking with 200 and 250 D.P.H.

Figure 19* shows the limiting alloy content permissible to prevent heat-affected-zone cracking with the large fillet weld. This limit of zero cracking is related to alloy content on a three-dimensional diagram, nickel and chromium contents being plotted on two axes, and the manganese content at the cracking limit is shown as contours of equal manganese content. It can be seen from Fig. 19 that, with low nickel contents, chromium additions up to 1·0% have little effect on the weldability of steels. This effect is also shown in Figs. 18*b* and *e*, which indicate that chromium has also little effect on normalized-plate hardness. These findings are in agreement with the work of Sims and Banta,[1] who observed that additions of chromium to a carbon–manganese steel had little effect on the weldability and yield stress.

Variations in nickel content over the range up to 1% have a greater effect on hard-zone-cracking severity and normalized-plate hardness than similar additions of chromium; above 1% nickel, however, additions of nickel and chromium to the steels have almost comparable effects on the weldability and hardness of the normalized plate.

The effect of variations in manganese content on the weldability and the hardness of the normalized plate is more marked than similar variations in nickel and chromium contents. This greater effect of manganese is true for the whole range of steels examined.

There is no obvious linear relationship between an increase in any one alloying element and a corresponding increase in normalized-plate hardness or severity of hard-zone cracking, except over a restricted range of composition. This result is not in complete agreement with the theory of carbon equivalents for determining weldability advanced by Dearden and O'Neill.[2] If the range of composition above 0·9% nickel, up to 1·0% chromium, and 0·7–1·1% manganese is considered the suggested carbon equivalents give a ratio nickel/chromium/manganese of 15/5·5/6 for a similar effect on weldability over this range, whereas according to Fig. 19 the ratio should be 9/5/4.

Hardenability/Cracking Relationship

The relationship between the maximum developed hardness in the heat-affected zone and the severity of cracking is given in Fig. 22. Analysis of the results obtained from the main series of manganese–nickel–chromium–molybdenum steels shows that an average maximum hardness of 370 D.P.H. in the hard zone can be taken as the safe upper limit for no cracking under the test conditions employed, and that the safe upper limit for maximum hardness is 380 D.P.H. The safe limits for the manganese–nickel–chromium–molybdenum steels containing copper, from the few results available, appear to be lower and are approximately 360 and 370 D.P.H. respectively. These values for limiting hardness are in good agreement with the work of Dearden and O'Neill[2] and also that of Reeve.[3]

It has been observed from the results that there is a general increase in severity of cracking with increasing plate hardness, although the scatter is rather wide. From these results safe upper limits of normalized-plate hardness, to avoid hard-zone cracking in the Reeve test, are 180 D.P.H. for the small fillet and 210 D.P.H. for the large fillet. The steels containing copper gave similar results, though the safe limit of plate hardness may be raised to 190 D.P.H. for the small fillet weld.

* To facilitate superimposition of Fig. 19 on Figs. 20 and 21, as dealt with later in the present paper, Fig. 19 is reproduced in the form of a transparency.

Table III

CRACKING IN WELDED ALLOY STEELS

No.	Steel: Approximate Composition, %				Hard-Zone Cracking in Reeve Test, % of leg length		Microstructure of Plate as Normalized
	Mn	Ni	Cr	Cu	Small Fillet	Large Fillet	
2	1·1	0·5	0·3	Nil	17	Nil	Pearlite in ferrite matrix (Fig. 6)
20	1·0	0·5	1·0	Nil	36	Nil	Troostite and traces of irresolvable martensite in ferrite (Fig. 7)
5	1·2	1·0	0·3	Nil	47	Nil	As above (Fig. 8)
28	0·9	0·9	0·2	0·9	23	½	Troostite and irresolvable martensite in ferrite (Fig. 9)
22	0·8	1·0	1·0	Nil	22	1	As above (Fig. 10)
11	1·2	0·6	0·7	Nil	32	5	Greater proportion of irresolvable martensite (Fig. 11)
14	1·0	1·1	0·6	Nil	40	14	Irresolvable martensite in ferrite (Fig. 12)
23	1·3	1·0	1·0	Nil	71	54	As above (Fig. 13)

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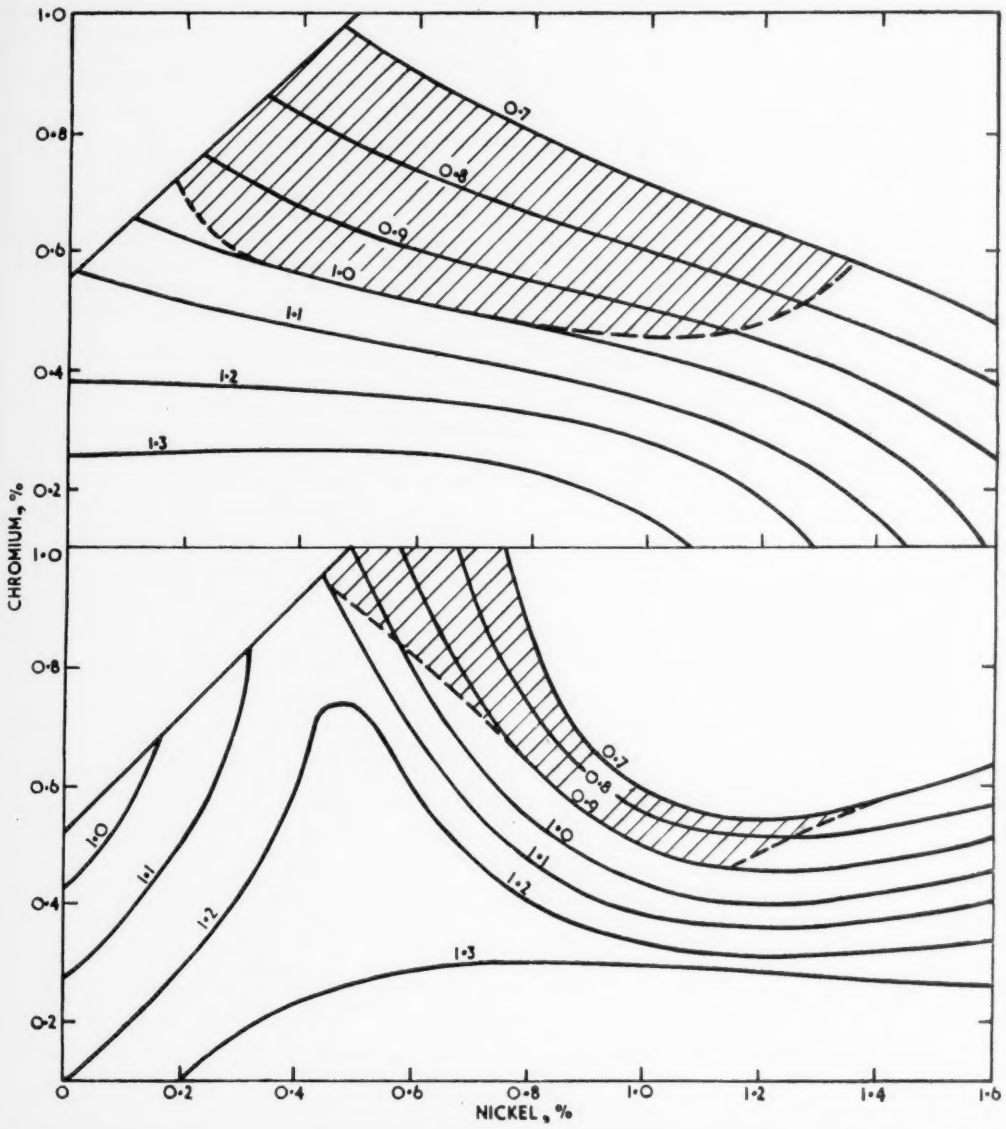

Fig. 20

Fig. 2

Figs. 20–21—Alloy-content/proof-stress diagram. Contours indicate percentage manganese content to give 0·3% proof stress of 30 tons/sq. in. on normalized specimens (Fig. 20), and 0·3% proof stress of 32·5 tons/sq. in. on normalized and tempered specimens (Fig. 21). Optimum-composition areas are shown hatched

It should be noted that these results are applicable only when the weldability test is carried out at room temperature, since the initial temperature of the plates has an effect on the rate of cooling in the heat-affected zone, which determines the structure of that zone and affects the susceptibility to cracking.

Examination of Microstructure

In Fig. 19, which relates incidence of hard-zone cracking to alloy content, it can be seen that variations of chromium content have different effects on the weldability of the steels, depending on the amount of nickel present. With 0·2–0·6% of nickel and 1·0–1·1% of manganese there is very little change in weldability of the steels with variations in chromium content from 0·2% to 1·0%. This is shown as a flat-topped hump in the diagram. Because of this effect, steels 2, 5, 11, 14, 20, 22, and 23 were selected for high-power-microscope examination of the normalized plate. These seven steels showed different amounts of cracking in the weldability test, and all had compositions adjacent to the hump in Fig. 19.

Although the manganese–nickel–chromium–molybdenum steels containing copper, for a given normalized-plate hardness, show less hardenability than similar steels without copper, the tendency of the two types

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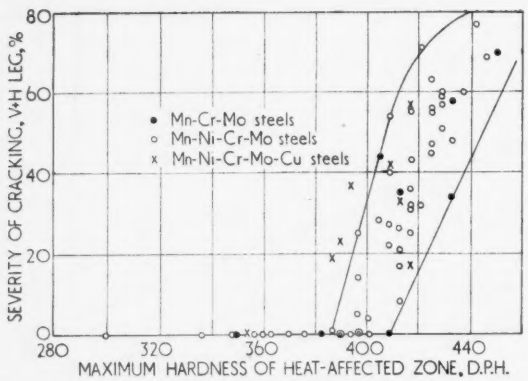

Fig. 22—Maximum heat-affected-zone-hardness/cracking relationship for all tests

of steel to hard-zone cracking is similar when they are compared on the basis of normalized-plate hardness. It appears that the addition of copper to a manganese–nickel–chromium–molybdenum steel increases the normalized-plate hardness and reduces the weldability but has no marked effect on the hardenability.

In the heat-affected zone of some of the higher-alloy steels of the series there was an apparent softening near the fusion line. Experiments by Tremlett[7] have shown that there was some retained austenite in the heat-affected zone of steel 9, and it is possible that this may be the cause of the softening in the higher-alloy steels. A copper-containing steel (steel 28) also examined showed slight hard-zone cracking with the large fillet weld.

The order of cracking severity for the steels examined, together with a short description of the microstructure observed, are given in Table III, from which it can be seen that the good weldability of the relatively highly alloyed steel 20 (manganese 1·00%, nickel 0·51%, chromium 1·00%) is explained on the basis of its microstructure in the normalized state, which is quite different from the microstructure of steel 11 (manganese 1·22%, nickel 0·55%, chromium 0·65%), when from considerations of composition similar microstructures might be expected. The structure of steel 22 consists mainly of troostite* in a ferrite matrix, while that of steel 11 is chiefly irresolvable martensite† in ferrite. Photomicrographs of the steels are shown in order of cracking severity in Figs. 6 to 13. It appears that the increase in severity of hard-zone cracking in the weldability test is accompanied by increasing amounts of irresolvable martensite and decreasing amounts of troostite in the steels as normalized, an observation consistent with the fact that cracking severity is related to hardenability, as shown in Fig. 22.

Reliability of the Results

It was thought that slight differences in the normalizing procedure, which was carried out industrially, may have given rise to variations in plate hardness. This would render the hardness values less comparable from one steel to another than they would have been if normalizing had been carried out under laboratory conditions. Some pieces cut from the test plates were therefore renormalized, but it was found that the resulting hardness values did not differ greatly from the recorded plate-hardness readings.

There is good agreement between the average maximum and the maximum values of hardness for the series of steels, and the upper limiting values of average maximum and maximum hardness for freedom from hard-zone cracking in the tests are not very different; this shows that there is very little scatter in the hardness readings taken in the region of maximum hardness in the heat-affected zones, and indicates that the method of hardness testing was satisfactory.

DETERMINATION OF MECHANICAL PROPERTIES

In order to satisfy the requirements of any particular application for which a weldable low-alloy steel would be used it was decided to observe the following mechanical properties on the series of steels:

(*a*) Proof stress at 0·02%, 0·1%, 0·2%, 0·3%, and 0·5% extension
(*b*) Ultimate tensile strength
(*c*) Ductility as elongation on a $4\sqrt{A}$ gauge length and reduction in area at fracture
(*d*) Notch impact strength.

In all mechanical tests sub-standard test pieces had to be used because of the limited amount of material available.

It was realized that any slight variation in the heat-treatment from one steel to another might affect the validity of the results when comparing alloy content with mechanical properties. Because of this it was decided to renormalize the test blanks before machining the test pieces, in order to ensure uniformity of heat-treatment. A normalizing temperature of 900° C. was chosen, though it was realized that this would not be the ideal temperature for all the steels. Owing to the relatively small size of the test blanks as compared with the original plates, the normalizing treatment given was likely to yield mechanical properties comparable with sections a little under ½ in. thick, owing to the faster cooling rates obtaining with the test blanks than with a ½-in. plate.

It was considered desirable to determine the mechanical properties in the normalized condition and the normalized and tempered condition, since the latter treatment has been reported by Sims and Banta[1] as giving better mechanical properties without adversely affecting the weldability. For this reason a series of

* In the present paper the decomposition products of austenite obtained by cooling a given steel at successively slower rates from above the A_3 transformation are taken to be martensite–troostite–fine pearlite–coarse pearlite. The decomposition of martensite on tempering a hardened steel at successively higher temperatures is assumed to proceed in the form martensite–sorbite–coalesced carbides.

† The term "irresolvable martensite" was used by Jones (reference 8) to describe a constituent observed in air-cooled carbon–manganese steels. The constituent has also been referred to by Greaves (reference 9). A scratch test carried out on a specimen containing the constituent indicated that it had the high hardness normally associated with martensite.

Table IV—EFFECT OF ALLOY CONTENT AND HEAT-TREATMENT ON MECHANICAL PROPERTIES

Alloy Content			Steel	Proof Stress, tons/sq. in.										Ultimate Tensile Strength, tons/sq. in.		Elongation on $4\sqrt{A}$, %		Reduction in Area, %		Notch Impact Strength				
				0·02%		0·1%		0·2%		0·3%		0·5%								Hounsfield Balanced Impact, ft.lb.				Izod Equivalent
Chromium	Nickel	Manganese																		1	2	3	Average	
				N.	N.T.	N.	N.T.	N.	N.T.	N.	N.T.	N.	N.T.	N.	N.T.	N.	N.T.	N.	N.T.	N.	N.	N.	N.	N.
Low	Low	Low	1	15·0	21·0	19·0	23·4	20·7	24·0	21·5	24·0	22·2	24·0	35·0	34·4	32	35	63	67	16·6	21·0	26·8	21·4	51
		Medium	2	16·0	27·0	21·7	29·5	24·8	30·0	26·6	30·0	28·5	30·0	43·3	40·4	25	28	55	60	12·2	11·8	13·8	12·6	30
		High	3	19·0	29·7	26·6	33·0	30·6	34·2	33·1	34·9	36·3	35·0	52·5	44·8	23	26	46	60	8·0	9·9	10·2	9·4	23
	Medium	Low	4	16·5	25·2	20·8	27·2	23·2	27·7	24·9	27·7	26·6	27·7	39·2	38·0	26	31	61	63	18·3	19·7	21·0	19·7	47
		Medium	5	16·5	28·5	22·5	30·0	26·3	30·0	28·5	30·0	30·9	30·0	45·2	41·2	26	30	55	65	14·1	12·2	9·2	11·8	28
		High	6	20·0	20·0	27·8	32·2	32·4	33·6	34·8	34·6	37·6	35·6	52·6	44·7	22	24	55	65	10·6	10·6	7·7	9·6	23
	High	Low	7	16·5	29·0	23·4	30·0	26·3	30·0	28·0	30·0	30·0	30·0	42·5	40·0	25	28	55	60	13·4	19·8	17·6	16·9	41
		Medium	8	17·0	29·5	26·0	33·0	29·2	34·0	31·3	34·6	34·5	35·0	49·5	44·5	23	28	49	59	6·1	6·7	4·8	5·9	14
Medium	Low	Low	10	19·3	30·5	24·5	31·0	27·3	31·2	29·2	31·4	31·4	31·7	45·4	41·0	28	29	55	66	12·3	13·2	13·3	12·9	31
		Medium	11	21·7	29·2	28·0	31·0	31·6	31·4	34·0	31·7	36·7	32·1	51·0	42·0	21	19	50	55	10·4	10·0	..	10·2	24
		High	12	23·0	34·5	29·3	37·1	33·2	38·2	35·8	38·8	38·6	39·5	57·2	47·5	21	23	49	54	10·9	7·7	..	9·3	22
	Medium	Low	13	17·5	31·8	24·3	32·7	28·0	32·9	29·8	33·0	32·0	33·0	44·5	40·5	24	28	56	62	21·0	16·5	20·6	19·4	47
		Medium	14	19·3	32·0	26·3	33·3	30·3	33·9	32·8	34·0	35·9	34·3	50·0	42·4	23	28	60	68	13·3	11·2	13·2	12·6	30
		High	15	27·0	33·2	36·0	36·2	41·5	37·5	44·5	38·1	48·0	39·0	62·7	48·5	18	20	45	50	5·6	5·1	5·4	5·4	13
	High	Low	16	22·0	32·0	26·6	32·0	29·5	32·0	31·1	32·0	33·0	32·0	44·5	40·0	25	29	55	64	15·4	14·6	18·0	16·0	38
		Medium	17	25·7	31·3	31·5	34·2	36·0	35·4	38·0	36·0	41·0	36·6	56·5	45·0	21	23	50	60	11·1	6·1	11·4	9·5	23
		High	18	28·0	32·2	36·0	36·3	42·0	38·0	45·0	38·7	48·0	39·5	62·7	49·0	17	23	45	56	3·7	4·0	2·9	3·5	8
High	Low	Low	19	22·5	30·2	28·0	30·7	31·0	31·0	33·0	31·0	35·2	31·0	48·4	41·0	25	27	55	65	13·0	14·0	12·2	13·1	31
		Medium	20	19·0	32·0	25·8	34·4	30·6	35·0	33·3	35·4	36·2	35·9	50·3	43·5	21	23	47	65	10·8	11·0	10·8	10·9	26
		High	21	25·0	32·2	34·0	36·3	39·5	37·8	42·5	38·7	46·5	39·9	62·3	48·5	20	21	50	59	6·0	5·2	5·2	5·5	13
	Medium	Low	22	18·5	32·0	27·1	34·0	30·1	34·5	32·0	34·7	35·0	35·2	52·4	45·4	21	29	55	63	10·2	8·6	9·2	9·3	22
		Medium	23	24·0	34·3	31·0	36·7	35·0	37·5	38·0	38·1	39·5	39·0	55·0	47·2	21	23	57	63	4·8	7·5	6·0	6·1	15
		High	24	32·2	37·0	41·0	40·5	46·5	42·0	50·0	42·5	52·0	43·2	69·4	51·4	17	23	54	64	4·5	4·0	4·2	4·2	10
	High	Low	25	20·9	31·0	30·1	35·0	35·2	37·0	38·0	37·5	41·2	38·5	57·2	46·6	20	25	50	65	6·0	10·5	8·0	8·2	20
		Medium	26	31·0	36·2	41·0	40·0	46·0	41·0	50·0	42·0	53·0	43·0	67·0	51·2	20	23	54	58	4·0	4·5	5·5	4·7	11
		High	27	37·0	38·0	46·0	41·5	50·6	43·0	53·5	43·5	56·7	44·0	71·4	52·4	20	28	60	62	3·0	4·3	3·5	3·6	9
Low*	Medium	Low	28	20·0	28·0	24·3	31·5	27·3	32·0	29·0	32·3	31·3	32·5	47·0	42·0	29	29	55	63	11·0	9·0	10·5	10·2	25
	High	Low	29	21·4	29·0	27·0	32·0	30·0	33·2	32·0	33·6	34·0	34·5	49·2	44·6	27	26	54	59	11·5	11·0	6·7	9·7	23
Medium*	Medium	Low	30	22·2	32·2	29·8	36·0	33·5	37·0	35·8	38·0	38·9	39·2	54·8	47·0	22	26	51	58	8·3	9·0	6·5	8·0	19
	High	Low	31	22·0	33·0	30·4	36·2	35·0	37·6	38·0	38·3	41·5	39·4	57·0	48·8	21	23	50	60	7·2	8·0	7·0	7·4	18
Low	Zero	High	33	16·7	31·7	25·0	34·5	30·0	35·7	32·5	36·3	35·8	37·1	50·8	45·8	21	24	45	54	5·2	4·7	4·3	4·7	11
Medium	Zero	Low	34	15·7	30·0	19·0	30·0	21·7	30·0	23·2	30·0	25·2	30·0	41·2	39·0	28	31	56	57	14·1	17·1	13·5	14·9	36
		Medium	35	22·0	34·5	28·9	36·4	31·7	36·8	33·5	37·2	36·2	37·7	50·8	45·8	22	25	53	57	9·4	10·0	8·0	9·1	22
		High	36	22·0	35·2	30·0	38·5	33·7	39·0	36·0	39·5	39·2	40·2	54·2	47·6	25	25	52	62	5·2	5·1	4·8	5·0	12

N. = normalized specimens; N.T. = normalized and tempered specimens * Copper-containing steels

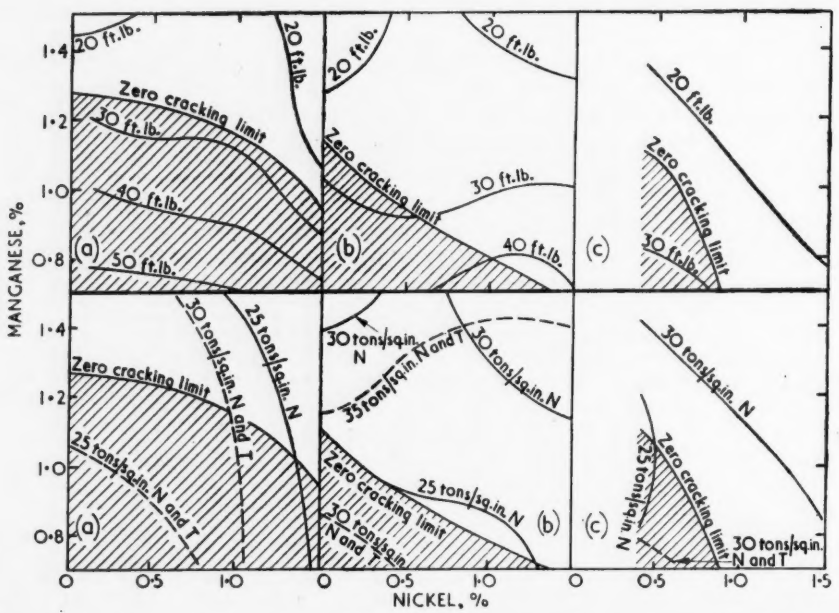

Fig. 23

Fig. 24

tempering* tests at intervals of 100° C. was carried out on steel 5, as a result of which 600° C. was chosen as the tempering temperature for the series of steels, though it was again realized that this temperature might not be ideal for every steel in the series. A standard tempering time of 1½ hr. was used throughout to allow sufficient time for diffusion even at the more usual tempering temperatures (400–500° C.).

Fig. 23—Alloy-content/mechanical-properties/cracking diagrams; equivalent Izod for (*a*) low, (*b*) medium, and (*c*) high chromium. Cracking limits are for large fillet welds

Fig. 24—Alloy-content/mechanical-properties/cracking diagrams; 0·1% proof stress for (*a*) low, (*b*) medium, and (*c*) high chromium. Cracking limits are for large fillet welds

EXPERIMENTAL PROCEDURE

Heat-Treatment

Test blanks ½ × ½ × 5 in. from each of the steels in the series were cut from the plates used in the weldability tests and were normalized by heating at 900° C. for 1 hr. in air in an electric muffle furnace, followed by cooling with free air circulation round the specimens. Tempering treatment was carried out on one test blank from each steel, by holding the normalized specimen at 600° C. in air for 1½ hr. in the electric muffle furnace, followed by cooling in free air. A larger test blank (½ × 1½ × 5 in.) was used for the series of tempering-temperature tests on steel 5. This blank was cut from the weldability test plates, normalized as previously described and then cut into eight sections, each ⅜ × ½ × 1½ in. The sections were tempered by holding for 1½ hr. at the respective temperatures, followed by cooling in free air. Tempering was carried out at 100°, 200°, 300°, 400°, and 500° C. in an air-circulating electric furnace and at 600°, 700°, and 800° C. in the electric muffle furnace.

Test Pieces and Method of Testing

Tensile test specimens of gauge diameter 0·2525 in. ($\frac{1}{20}$ sq. in. area) were cut from the normalized, and the normalized and tempered blanks. Extensometer readings were taken on a gauge length of 1 in. and the elongation to fracture was measured on a gauge length of $4\sqrt{A}$. Notch impact test pieces were cut from the same blanks in the normalized condition only, the test specimen in this instance being 1¾ in. long by $\frac{5}{16}$ in. diameter, with a notch angle of 45° and a root radius of 0·25 mm. The tensile specimens for the tempering tests on steel 5 were of a smaller size in order to obtain the larger number of specimens from the material available, and had a gauge diameter of 0·1785 in. ($\frac{1}{40}$ sq. in. area). The extensometer readings were taken on a gauge length of ½ in. and the elongation was again determined on a $4\sqrt{A}$ gauge length.

The tensile testing was carried out on a 5-ton Denison machine, and stress/strain curves were plotted using a Lindley extensometer with a special attachment for sub-standard specimens. The values of proof stress observed from these curves were for 0·02%, 0·1%, 0·2%, 0·3%, and 0·5% extension. The proof stress for 0·02% extension on the smaller specimens from the series of tests on steel 5 was not observed, as its accuracy would have been doubtful owing to the short gauge length. The notch impact tests were carried out on a Hounsfield balanced impact machine, the energy of blow being 48 ft.lb. The values obtained were converted to equivalent Izod values by multiplying by a factor of 2·4.

Metallographic Examination of Steel 5

Specimens were cut from the unstrained ends of the tensile test pieces used in the series of tempering tests

* The term tempering has been used for consistency to refer to heat-treatments given to the steels after normalizing, though it is realized that heat-treatment above the A_1 transformation point should not strictly be referred to as tempering.

Fig. 25

Fig. 26

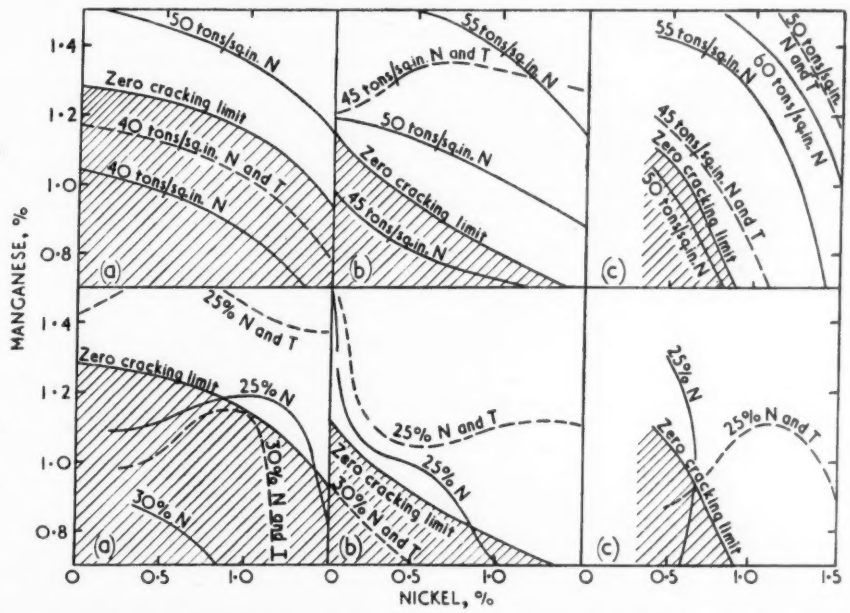

Fig. 25—Alloy-content/mechanical-properties/cracking diagrams; ultimate tensile stress for (*a*) low, (*b*) medium, and (*c*) high chromium. Cracking limits are for large fillet welds

Fig. 26—Alloy-content/mechanical-properties/cracking diagrams; elongation for (*a*) low, (*b*) medium, and (*c*) high chromium. Cracking limits are for large fillet welds

on steel 5. The specimens were mechanically polished and etched in 2% nital.

EXPERIMENTAL RESULTS

Full results of all the tests are given in Table IV and a summary of the tests is presented in Table II, for comparison with the welding tests.

Relationship Between Alloy Content and Mechanical Properties of Steels in Normalized Conditions

The relationship between impact strength, alloy content, and weldability of the steels in the normalized condition is shown in Fig. 23, and in Figs. 24–26 strength and ductility are related to alloy content and weldability for the steels in the normalized and normalized and tempered conditions. These diagrams were obtained by taking a constant value for chromium and plotting nickel against manganese, and three diagrams will thus cover the range of steels, since there are only three levels of chromium content. Curves were then plotted representing the various mechanical properties, together with a comparison curve for limit of hard-zone cracking in the large fillet weld in the weldability test. The areas where there is freedom from cracking are cross-hatched and are always on the origin side of the cracking-limit line. The diagram shown in Fig. 19 gives a three-dimensional relationship between alloy content and weldability, and can be compared with Figs. 20 and 21, which have the same axes as Fig. 19 and relate alloy content to proof stress for both the normalized and the normalized and tempered steels.

It has been observed that a 0·3% proof stress of 30 tons/sq. in. can be obtained by substituting the manganese, nickel, and chromium contents for each other in definite proportions. This effect can be seen in Fig. 20. If the alloying elements are substituted for each other in the proportion 20 nickel/7 chromium/5 manganese over most of the range examined, then the 0·3% proof stress value after normalizing should be very little changed. This ratio approximates to that given by Dearden and O'Neill[2] for tensile properties and indicates that the addition of nickel has little effect on proof stress as compared with the effects of manganese and chromium.

Addition of 1% of copper to steels 4, 7, 13, and 16

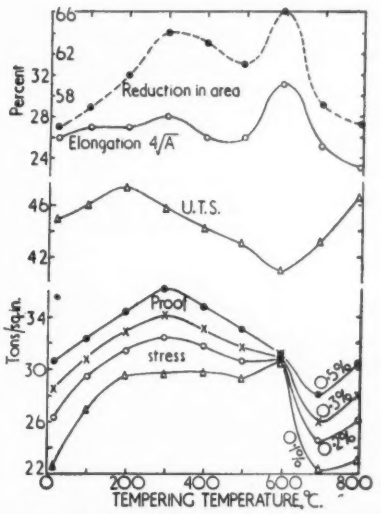

Fig. 27—Effect of tempering temperature on mechanical properties of normalized plate (steel 5)

raised the 0·3% proof stress by 4–7 tons/sq. in., an effect less than that for a similar addition of chromium or manganese. Additions of manganese give the greatest increase in ultimate strength, while similar additions of nickel and chromium have much less effect on this property. The addition of copper also considerably increases the ultimate strength. Additions of nickel, chromium, and manganese all tend slightly to reduce ductility, and when impact strength is considered the reduction is more marked, manganese and chromium having the greatest effect and nickel the least. The addition of copper to steels 4, 7, 13, and 16 had little effect on ductility, but reduced the impact strength considerably. It should also be noted that the weldability was adversely affected by this addition of copper.

Effect of Tempering Temperature on Mechanical Properties and Microstructure of Steel 5

The work carried out on steel 5 in order to determine the most beneficial tempering temperature yielded some interesting results. The effect of different tempering temperatures on the strength and ductility of this steel is shown in Fig. 27, and if a proof stress for 0·1% extension is taken as a criterion optimum conditions are obtained by tempering at 600° C.; this treatment also gives good ductility but low ultimate strength. With this tempering temperature alone a definite yield point appears. If, however, the proof stress for greater extensions is chosen (*e.g.*, 0·3% or 0·5%) the optimum tempering temperature becomes 300° C. It is possible that tempering at about 300° C. may reduce the impact strength of the steel, and for this reason is undesirable. Although treatment at 300° C. produces the highest value of 0·5% proof stress, the value for 0·1% proof stress is lower than that obtained by treatment at 600° C.

Tempering treatment at temperatures higher than 600° C. gives a severe drop in proof stress for all values of extension, minimum values being reached at 700° C. The value of proof stress for each extension value obtained by treatment at 700° C. is less than that obtained in the normalized condition, this decrease in proof stress being less marked with the higher extension values. For a 0·1% proof stress there is a difference of approximately 8 tons/sq. in. between specimens treated at 600° C. and those treated at 700° C., the corresponding difference for a 0·5% proof stress being only about 3 tons/sq. in.

It is interesting to note that the minimum value of ultimate tensile strength corresponds with a maximum value of ductility at a tempering temperature of 600° C., but the minimum value of proof stress is obtained by tempering at 700° C. This is because the values for ultimate tensile strength were calculated on the original area of cross-section. If actual breaking-stress values are considered the curve would be changed considerably.

The variation of microstructure with tempering temperature of normalized steel 5 shows good correlation with the resulting mechanical properties. The microstructures obtained with the various tempering temperatures are shown in Figs. 14 to 17, and it can be seen that the microstructure as normalized consists of masses of dark etching troostite with smaller light etching areas of irresolvable martensite, in a ferrite matrix. As the tempering temperature is raised the martensite decomposes to give sorbite, and the improved strength with a tempering temperature of 300° C. may be due to partial decomposition of the martensite areas. When a tempering temperature of 600° C. is reached the decomposition of the martensitic areas is complete and this state corresponds with the production of a definite yield point and maximum ductility in the tensile test.

On tempering at 700° C. spheroidization of the carbides takes place, an effect corresponding with a reduction in proof stress to a minimum for all values of extension and with a reduction in ductility. Treatment at 800° C., which is no longer tempering but rather low-temperature normalizing, produces a structure composed of irresolvable martensite with some troostite in a ferrite matrix, giving slightly higher proof-stress values and a minimum ductility.

Effect of Tempering at 600° C. on Mechanical Properties

The proof stress is increased by tempering the lower-alloy steels of the series at 600° C. There is an increase in proof stress for most values of extension, and the greatest increase is associated with the smallest extension value. This effect is indicated by the stress/strain curve altering from a non-ferrous type (continuous curve) to a mild-steel type (with a definite yield point). With the higher-alloy steels of the series there is a decrease in proof stress on tempering, this decrease being more marked the greater the value of the extension. This effect is again accompanied by a tendency to form a yield point.

The yield point produced in the lower-alloy steels by tempering after normalizing is at a stress level corresponding to a large extension (0·5%) proof stress for the same steel as normalized. As the alloy content is increased the yield point occurs at relatively lower

Table V

PROOF-STRESS VALUES WITH DIFFERENT-SIZED SPECIMENS

Specimen Size		Proof Stress, tons/sq. in.		Ultimate Tensile Strength, tons/sq. in.	Elongation on $4\sqrt{A}$, %	Reduction in Area, %
Gauge Diameter, in.	Extensometer Gauge Length, in.	0·1%	0·5%			
0·2525	1·0	30·6	31·0	40·9	31	66
0·1785	0·5	30·0	30·0	41·2	30	65

Table VI

WELDABILITY AND MECHANICAL PROPERTIES IN NORMALIZED CONDITION

Steel				Mechanical Properties				Weldability in Reeve Test with Large Fillet Weld
No.	Approximate Composition, %			Proof Stress, tons/sq. in.		Equivalent Izod Value, ft.lb.	Elongation on $4\sqrt{A}$, %	
	Mn	Ni	Cr	0·02%	0·3%			
10	0·8	0·5	0·7	19·3	29·2	31	28	No cracking
19	0·7	0·6	1·0	22·5	33·0	31	25	No cracking
20	1·0	0·5	1·0	19·0	33·3	26	31	No cracking
11	1·2	0·6	0·7	21·7	34·0	24	21	5% Cracking
35	1·2	0·1	0·6	22·0	33·5	22	22	2% Cracking

stress levels compared with the proof stress of the normalized steel.

The cause of the change in relationship between the proof stress in the normalized condition and the yield point in the normalized and tempered condition with variation in alloy content can be traced to the normalizing treatment. Normalizing the higher-alloy steels produces a hardening effect owing to the rate of cooling, which does not occur to the same extent with the lower-alloy steels of the series. Tempering at 600° C. removes most of this hardening and tends to give an equilibrium structure.

A slight decrease in ultimate strength is caused by tempering the lower-alloy steels of the series. As the alloy content of the steels is increased this effect becomes more marked, and there is a reduction of almost 20 tons/sq. in. in the ultimate strength of the steel with the highest alloy content. This is in agreement with the hardening effect due to normalizing.

There is a slight increase of about 3% in elongation with the lower-alloy steels on tempering at 600° C. after normalizing. This increase becomes greater with the higher-alloy steels and reaches 8% with the highest alloy steel of the series. The reduction in area of all the steels is increased by tempering, but there is little variation of this increase with change in alloy content.

Only a few of the steels have been examined microscopically in the tempered condition, but with these steels almost complete decomposition of the irresolvable martensite has taken place. The steels examined in the tempered condition include steels 11 and 28, which contained considerable amounts of this constituent after normalizing (*see* Figs. 11 and 9).

The results indicate that the relationship between microstructure and mechanical properties observed with steel 5 occurs with the other steels of the series, which suggests that the presence of irresolvable martensite in the microstructure is associated with a continuous type of stress/strain curve with a low limit of proportionality. When this constituent is decomposed by tempering a stress/strain curve having a definite yield point is produced.

Reliability of Results

It was realized that the use of miniature specimens for proof-stress determinations and impact tests may have impaired the reliability of the results. However, the good agreement between proof-stress values obtained on the two different-size tensile specimens of steel 5 tempered at 600° C. gives an indication of the reproducibility of the results; these values are given in Table V. In most instances there was good agreement between each of the three impact tests carried out on each steel, which indicates that the testing method was satisfactory.

It should be noted that the mechanical properties observed for the steels in the normalized condition will apply only to steel plates slightly less than ½ in. thick, owing to the faster cooling rates occurring in

Table VII

WELDABILITY AND MECHANICAL PROPERTIES IN TEMPERED CONDITION

Steel				Mechanical Properties (Tempered)			Weldability in the Reeve Test with Large Fillet Weld
No.	Approximate Composition, %			Proof Stress, tons/sq. in.		Elongation on $4\sqrt{A}$, %	
	Mn	Ni	Cr	0·02%	0·3%		
13	0·7	1·1	0·6	31·8	33·0	28	No cracking
20	1·0	0·5	1·0	32·0	35·4	23	No cracking
22	0·8	1·0	1·0	32·0	34·7	29	1% Cracking
35	1·2	0·1	0·6	34·5	37·2	25	2% Cracking

the normalizing process for the bars of ½ in. square section than would occur in ½-in. thick plates, and this faster cooling rate would tend to give higher strengths.

DISCUSSION

Weldability and Mechanical Properties

The data from the weldability tests and the mechanical tests can be analysed to determine the best combination of weldability and mechanical properties, either by examining the tabulated results or by superimposing Fig. 19 on Figs. 20 and 21. By using the first method the selected steels in Table VI give the best combination of weldability and mechanical properties in the normalized condition. If, however, consideration is given to weldability and the mechanical properties in the tempered condition, the steels included in Table VII are of most interest.

Good weldability combined with high mechanical properties in both the normalized and the normalized and tempered conditions is obtained with steels 20 and 35. Steel 20 has a high chromium content, which might be undesirable economically, but from this viewpoint steel 35 appears satisfactory, since with this steel high mechanical properties are obtained with medium chromium and manganese and low nickel contents.

In regard to the second method of analysis, that of superimposing Fig. 19 on Figs. 20 and 21, it will be observed that results are not available for the high-chromium low-nickel corners of the diagrams, since compositions in this range were not included in the series, but optimum combinations of mechanical strength and weldability can be observed. Those optimum compositions lie within an area bounded by the intersection of equivalent contour lines and a line representing the limit of compositions investigated. Within this area points on the zero cracking surface must be more distant from the origin (zero manganese, nickel, and chromium) than points on the mechanical-property surface. Figures 20 and 21 should be regarded as solid models with the manganese contours representing the important surface of each diagram. In each figure points on the surface indicate the alloy content of an infinite number of steels which all have the same proof-stress value (30 tons/sq. in. as normalized for Fig. 20 and 32·5 tons/sq. in. as normalized and tempered for Fig. 21. Steels with compositions lying above the surface have a higher proof stress than steels with compositions on the surface, and steels below the surface have a lower proof stress. Therefore steels with the best mechanical strength are those which lie above the surface indicated by the manganese contours in Figs. 20 and 21.

Figure 19 is similar to Figs. 20 and 21, except that in this instance the surface represents the alloy content of an infinite number of steels which just fail to give hard-zone cracking on ½-in. thick plates when BEAMA–IOW E217 electrodes are used. Compositions above this surface indicate steels which would give cracking in the test, and compositions below the surface show steels which are free from hard-zone cracking in the test. Therefore steels having the best weldability are those which lie below the surface indicated by the manganese contours in Fig. 19.

In order to obtain a steel with good strength combined with good weldability it is necessary that the composition should lie (*a*) above the surface indicated in Fig. 20 or 21 and (*b*) below the surface in Fig. 19. Therefore when Fig. 19 is placed over Fig. 20 or 21 it is necessary only to note the area where the manganese contours in Fig. 19 have a higher value for given nickel and chromium contents than those in Figs. 20 and 21.

If the mechanical properties of the steels in the normalized condition are compared with their weldability, using the method just described, an optimum composition range can be derived. This optimum range, which gives a 0·3% proof stress of 30 tons/sq. in. with no cracking in the weldability test, is shown hatched in Fig. 20, and is defined by the following limits of alloy content: Manganese 0·8–1·0%, nickel 0·6–1·0%, chromium 0·4–1·2%. In these ranges of composition it is necessary for high manganese contents to be present with low nickel contents, and *vice versa*. It will be observed that steel 35 is not included in this range of compositions, although its mechanical strength is high and its weldability fair. The reason is that the surface represented in Fig. 19 is for compositions which give no hard-zone cracking in the weldability test. A similar surface plotted for small amounts of cracking (*e.g.*, 5%) would be considerably altered in its position and would include the composition of steel 35 in the optimum range of composition, when superimposed on Fig. 20.

If the mechanical strengths of the steels in the tempered condition are considered, placing Fig. 19 over Fig. 21 shows the range of compositions to give a 0·3% proof stress of 32·5 tons/sq. in. This range, which is shown hatched in Fig. 21, is more limited than that shown in Fig. 20 for the lower proof stress (30 tons/sq. in.). This smaller optimum range in Fig. 21 would be inside the larger range derived from Fig. 20, but would be displaced towards the higher nickel and chromium and lower manganese region. The composition approximately in the centre of this smaller optimum range is as follows: Manganese 0·8%, nickel 0·8%, chromium 0·8%, and a steel with this composition should give the best combination of weldability and mechanical strength in the normalized and the normalized and tempered conditions.

Microstructure in Relation to Weldability and Mechanical Properties

The good correlation shown between weldability and microstructure is interesting, since there is no obvious linear relationship between alloy content and weldability over most of the range explored. Most structural steels lie within the composition range of the steels tested, and it would appear that with the majority of these structural steels the microstructure of the normalized plate can also be related to the weldability.

In the weldability test two degrees of severity were imposed by using two sizes of welding electrode. The welds made with the larger electrode, because of the higher arc current, had a greater heat input than those made with the smaller electrode, the energy inputs being approximately $1·8 \times 10^5$ and $1·0 \times 10^5$ joules,

respectively. Because of this higher heat input welds made with the larger electrodes would have a slower rate of cooling in the weld zone than welds made with the smaller electrode. These different rates of cooling caused considerable difference in the hardness in the heat-affected zones of welds made with two sizes of electrode. The difference in average maximum hardness may be up to 75 hardness numerals when the values for the hard zone of two welds made with the two different sizes of electrode (10 S.W.G. and 6 S.W.G.) are compared.

The results of the tests have shown that the microstructure of the normalized plate, for the same amount of hard-zone cracking, is quite different under these two different conditions of severity. This variation in microstructure can be observed if Figs. 6 and 12 (steels 2 and 14) are compared.

Troostite is present in decreasing quantities and irresolvable martensite in increasing quantities in steels 20, 5, 28, 22, and 11 with the steels in this order. With the steels in this same order the severity of hard-zone cracking in the weldability test increases.

The results indicate that, within the range of steels examined, it should be possible to predict the weldability of a given steel under the test conditions employed, by examining the microstructure of the plate in the normalized condition. The possibility of relating weldability to the microstructure of normalized plate is important, because the results tend to show that the very severe restraint imposed in the Reeve test is not the major factor in the initiation of cracking. This observation is based on the fact that coarse cracking is associated only with the vertical leg of the fillet weld, whereas in the horizontal leg very extensive micro-cracking can be present. The major contraction stress in the vertical leg is perpendicular to the cracking plane and that in the horizontal leg in the plane of cracking. The results indicate that the severe tension in the vertical leg of the Reeve test is necessary only to widen the cracks, and is not necessary to initiate them. This is shown because extensive micro-cracking can occur in the horizontal leg, where the major stress is a shear stress parallel to the plane of cracking. If rate of cooling is the dominant factor in the initiation of hard-zone cracks, then it is to be expected that the severity of cracking could be related to the microstructure of the normalized plate.

With steel 5 the microstructure can be related to the mechanical properties obtained by various heat-treatments. This effect is shown by comparing Fig. 27 with Figs. 14 to 17.

With the steel initially in the normalized condition, tempering at successively higher temperatures causes the unresolved martensite in the microstructure to decompose, giving sorbite. When this change has gone to completion by tempering at 600° C. the steel exhibits a definite yield point in the tensile test. The yield point produced with steel 5 by tempering at 600° C. after normalizing raises the 0·1% proof stress from 22·5 to 30 tons/sq. in., which is the same value as that of the 0·5% proof stress of the normalized steel. This is a useful improvement if the steel is needed for a structure where 0·1% extension must not be exceeded. By tempering at temperatures above 600° C. this marked improvement in the 0·1% proof stress is lost, the deterioration coinciding with spheroidization of the carbides. For this reason the tempering temperature is rather critical on the upper side of 600° C., whilst if tempering is carried out much below 600° C. it is thought that the impact properties of the steel might suffer.

Because the temperature of tempering is rather critical with steel 5 it is possible that 600° C. is not the ideal tempering temperature for treating the whole range of steels. However, this treatment has given consistent mechanical properties with the series of steels, even though traces of irresolvable martensite have been seen in some of the steels in the tempered condition.

It is possible that the relationship shown between the microstructure and the formation of a definite yield point in steel 5 by tempering the steel at 600° C. after normalizing does not reveal the fundamental significance of this treatment. If the recent theory proposed by Cottrell,[10] which regards dislocations and their associated atmospheres of solute carbon atoms as being responsible for the existence of a yield point, is accepted then the tempering time at various temperatures may be an important factor.

At the lower temperatures a much longer time would be necessary to diffuse sufficient solute carbon atoms to the dislocations for the production of a definite yield point. The time at the various tempering temperatures in the tests with steel 5 was maintained constant at 1½ hr., and it is therefore possible that only at a temperature of 600° C. was the diffusion rate of the solute atoms sufficiently rapid for the change to be completed in 1½ hr. This suggestion is partly supported by the indications given in Fig. 27, which show that with tempering temperatures above 300° C. the proof-stress values for various extensions tend to approach a single value. This could mean that changes are taking place at temperatures above 300° C., but that sufficient time has not been given at temperature for the attainment of equilibrium conditions.

CONCLUSIONS

From the work reported the following conclusions can be drawn:

(1) Of the series of manganese–nickel–chromium–molybdenum steels containing 0·25% of molybdenum and 0·15% of carbon, that giving the best combination of weldability and mechanical strength when normalized in ½-in. square sections should contain 0·8% of manganese, nickel, and chromium respectively.

(2) The 0·1% proof stress of the normalized lower-alloy manganese–nickel–chromium–molybdenum steels of the series can be much improved by tempering at 600° C. Since it is only these lower-alloy steels which have good weldability, this improvement in 0·1% proof stress is common to all the weldable steels tested.

(3) With the higher-alloy manganese–nickel–chromium–molybdenum steels the proof stress for the greater values of extension is lowered by tempering the normalized steels at 600° C. This is because these steels have air-hardening character-

istics and are therefore hardened by the normalizing treatment and subsequently softened by tempering.

(4) The ductility of the steels in the normalized condition is improved by tempering at 600° C., and the ultimate tensile strength is lowered. These two effects are slight with the lower-alloy steels of the series.

(5) The copper–manganese–nickel–chromium–molybdenum steels tested did not give as good mechanical strength for equivalent weldability as the manganese – nickel – chromium – molybdenum steels. Tempering these copper-containing steels at 600° C. improves the proof-stress properties in the normalized condition.

(6) For all the steels tested there is good correlation between the microstructure of the plates in the normalized condition and the severity of hard-zone cracking obtained under the test conditions employed. The hardness of the plate in the normalized condition also bears some relation to the severity of cracking.

(7) With the small fillet weld (10 S.W.G. electrode) the upper limit of normalized-plate hardness for no hard-zone cracking is approximately 180 D.P.H. The upper limit of normalized plate hardness for no cracking with the large fillet weld (6 S.W.G. electrode) is approximately 210 D.P.H. These values of hardness for normalized ½-in. thick plate apply only to tests carried out at room temperature.

(8) The results indicate that approximate limiting values of hardness permissible in the hardened zone, in order that there shall be no hard-zone cracking under the test conditions employed, are as follows :

Steel Type	Heat-Affected-Zone Hardness, D.P.H.	
	Max.	Average Max.
Mn–Cr–Mo	380	360
Mn–Ni–Cr–Mo	380	370
Mn–Ni–Cr–Mo–Cu	370	360

These results are independent of electrode size (fillet size), and may therefore be used for determining the probable weldability of steels within the range of composition examined, on structural joints of similar severity to the Reeve test.

WORK ARISING OUT OF THE RESEARCH

As a result of this investigation reported some large-scale work has been planned. Two 2-ton high-frequency induction melts of steel have been made to confirm the results for weldability and mechanical properties of the experimental steels on an industrial scale. The two steels chosen for this further investigation have compositions similar to steel 35 and the optimum composition derived from a comparison of the alloy-content/cracking and alloy-content/proof-stress diagrams (Figs. 19, 20, and 21).

The mechanical strength of the steels from the two larger casts when normalized in the form of plates slightly less than ½ in. thick should be as indicated by the results in the present paper. However, when these steels are normalized in thicker sections lower mechanical strengths will probably be obtained. For this reason further work is being undertaken on the series of experimental steels in order to determine the mechanical properties when normalized under thermal conditions approximating to those occurring in 1½-in. thick plates. When this work is completed it should be possible to define a further range of composition in which a steel will combine good weldability in the test used in the investigation reported with good mechanical strength when normalized in thick sections.

Acknowledgments

The authors are indebted to Messrs. Colvilles, Ltd., the Mond Nickel Co., Ltd., and the United Steel Companies, Ltd., for the supply of experimental steels and for chemical analyses, and further to the Mond Nickel Co., Ltd., for making available the results of the tests on steel 9, which are included in order to present a complete series. The helpful suggestions and discussion of the results by the F.M.8 Committee of the British Welding Research Association and the Steering Committee of the Ministry of Supply on High Tensile Structural Steel Investigation are also acknowledged. Thanks are also due to Mr. J. S. Moses, who made the test welds, and to the staff of the British Welding Research Association for assistance with the work.

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Effect of Welding on Health

The results of an investigation consisting of a survey of the various types of welding followed by a clinical examination of about 250 welders in different industries, supplemented in many cases by special examinations such as radiological examination of the chest, and blood examinations, have been published under the title "The Health of Welders," by H.M.S.O.

It is concluded that welders do not suffer from any specific disease that could be described as 'welders' disease,' nor does occupational dermatitis appear to be a frequent disability. The main risk of ill health among welders is caused by fumes ; general recommendations are made, but the chief remedy is ventilation.

Faults in Arc Welds

The British Welding Research Association has issued a wall chart illustrating, with 37 half-tones, common faults in the metal-arc welding of steel. Copies of the chart, price 7*s.* 6*d.* post free, may be obtained from the B.W.R.A., 29 Park Crescent, London, W.1.

ANDREW CARNEGIE RESEARCH REPORT

Softening of Metals During Cold-Working

By N. H. Polakowski, Dipl. Ing.

SYNOPSIS

Steels and non-ferrous metals initially overstrained by tension, torsion, or drawing were progressively compressed in a direction opposite to that of the initial flow. In each case not only was a Bauschinger effect observed, but also an initial gradual decrease of the indentation hardness (by amounts up to 10%), before it increased. Both effects were reproducible and were more pronounced in the higher-carbon steels.

A theory relating indentation hardness and the energy stored in a cold-worked metal is put forward as a tentative explanation of both the Bauschinger effect and work-softening. To satisfy this theory quenched and tempered steels should soften during the early stages of cold-working, and they are shown experimentally to do so.

This energy concept accounts for the low rate of work-hardening during reversed- and cross-rolling of sheets, reversed deep drawing, and during cold-working and fatigue testing of heat-treated, *i.e.*, sorbitic and troostitic, steels. The softening effect provides an explanation of the recrystallization and mechanical properties of single- and polycrystalline metals after reversed deformation.

Introduction

THE investigation reported in this paper was undertaken to elucidate the following effects and to determine whether they were in any way related to each other :

(i) The recrystallization temperature of a metal usually decreases with increasing cold work, but a reversal of the direction of deformation causes an increase of the recrystallization temperature over that at the end of the first straining,[1–5] indicating that the metal has softened during the reversal.[6, 7] Yet it is claimed that work-hardening, as shown by mechanical properties, should continue to increase in spite of the raised recrystallization temperature and the Bauschinger effect.[2–5, 8, 9]

(ii) Deep-drawing practice has shown that ' reversed drawing ' facilitates deeper draws without interstage annealing than the unidirectional method.[10–12] It is also known that unidirectionally rolled sheets are harder than those whose direction of rolling is altered after each pass.[13–16]

(iii) The slope of the hardness-deformation curve is low or even negative in the early stages of deformation in carbon- and low-alloy steels heat-treated to over 300 DPH.[17–22]

The present experimental work was therefore initially concentrated on the behaviour of steel and some non-ferrous metals subjected to large reversed deformations. Apart from a study of the influence of the Bauschinger effect (*B*-effect) upon the stress/strain relations, systematic Vickers hardness determinations were made throughout the experiments. Later, the programme was extended to include compression tests on heat-treated steels (300–500 DPH) as well as a series of rolling tests on hardened and tempered steel strip.

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Mr. Polakowski is engaged in the study of deformation of metals at the University College of Swansea.

Notation

The following notation is used :

ψ = relative linear strain (deformation), equal to h_i/h in compression, and to $A_i/A = L/L_i$ in tension, where h, A, and L denote the actual height, cross-sectional area, and gauge length, respectively, of the test piece at any stage of deformation, and the suffix ' i ' denotes the initial value of the appropriate dimension

Δ, % = percentage strain = $100\,(\psi - 1)/\psi$ %

DPH = diamond pyramid (Vickers) hardness number

S = actual mean stress, tensile or compressive, tons/sq. in.

S_0 = yield stress—identical with S in tension up to the point of maximum load, and equal to S in compression when there is no friction between the test piece and the plates

Y_0 = initial (lower) yield point

S-curve (or S_0-curve) represents S (or S_0) as a function of strain

H-curve represents DPH as a function of strain

SH curve represents DPH as a function of S (or S_0)

Suffixes

v denotes test on a virgin material

ψ ,, test on a sample overstrained by an amount ' ψ ' (value indicated in each case)

t ,, tension

c ,, compression

s ,, torsion.

Example

H_{vc} denotes a curve representing DPH as a function of strain the test being a compression test on a ' virgin ' material

$S_{\psi c}$, $\psi_t = 1{\cdot}25$ means a compressive stress/strain curve, the test being performed on a specimen overstrained by preceding tension. The reduction of area during tension was $\Delta\% = 100 \times 0{\cdot}25/1{\cdot}25 = 20\%$.

The Bauschinger Effect

Bauschinger discovered that the effects of cold work are directional and that plastic deformation which raises the yield stress in the direction of flow reduces it in the opposite direction, when tension follows compression or *vice versa*, when torsion is followed by reversed torsion, and so on. The *B*-effect is explained

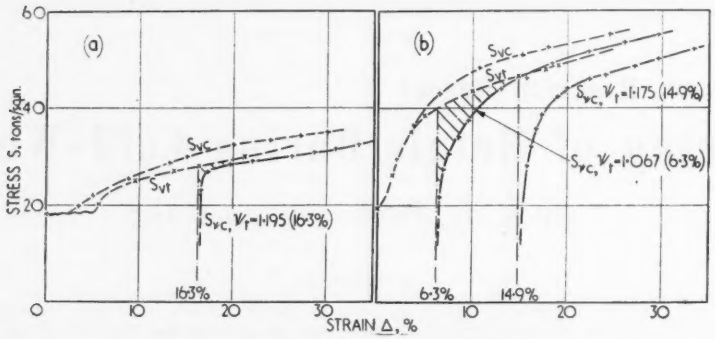


Fig. 1—Bauschinger effects during compression following tension; the shaded areas show the relative magnitude of the effect for different steels. (*a*) Low-carbon steel 007*r*, (*b*) high-carbon steel 088*a*

by the action of internal stresses locked-up in a cold-worked metal.[23–29]

As seen in Fig. 1, the subsequent compression curves $S_{\psi e}$ do not form a smooth continuation of the appropriate 'virgin' (tensile) curves S_{vt} but are initially much below those for continuously uni-directional deformation.

The relative magnitude of the *B*-effect in different materials can be roughly estimated by comparison of the shaded areas. It is small in mild steel (Fig. 1*a*) but very pronounced in the higher-carbon samples (Fig. 1*b*), this being in agreement with earlier results.[30, 31]

As areas beneath stress/strain diagrams are equivalent to energy values (= work of deformation) this representation leads to a broader concept of the *B*-effect and its relation to deformation energy.

EXPERIMENTAL PROCEDURE AND MATERIALS

Compression tests were carried out on cylinders prepared from $\frac{3}{8}-\frac{5}{8}$-in. dia. rods overstrained by tension, torsion, or drawing through a die. The load was applied in small increments, the ends of the

Table I

ANALYSIS OF CARBON STEELS USED IN EXPERIMENTS

Steel	C, %	Mn, %	Si, %	S, %	P, %
AR	0·013	0·026	trace	0·032	0·008
007	0·07	0·31	0·027	0·045	0·021
011	0·105	0·47	...	0·063	0·019
013	0·13	0·59	...	0·040	0·045
014	0·14	0·29	trace	0·050	0·020
018	0·18	0·56	0·06	0·041	0·014
018*d*	0·18	n.d.	n.d.	n.d.	n.d.
024	0·235	0·70	0·16	0·037	0·045
028	0·28	0·63	0·24	0·038	0·039
035	0·35	0·69	0·17	0·035	0·040
044	0·44	0·56	0·21	0·050	0·033
045	0·45	0·76	0·18	0·029	0·038
053	0·525	0·75	0·18	0·026	0·038
071	0·71	0·70	0·15	0·034	0·029
088	0·88	0·30	0·19	0·024	0·019
093	0·93	0·65	n.d.	n.d.	n.d.
115	1·10–1·20	n.d.	n.d.	n.d.	n.d.
125	1·26	0·29	0·12	0·020	0·016
145	1·45	0·37	0·25	0·022	0·017

n.d. = Not determined

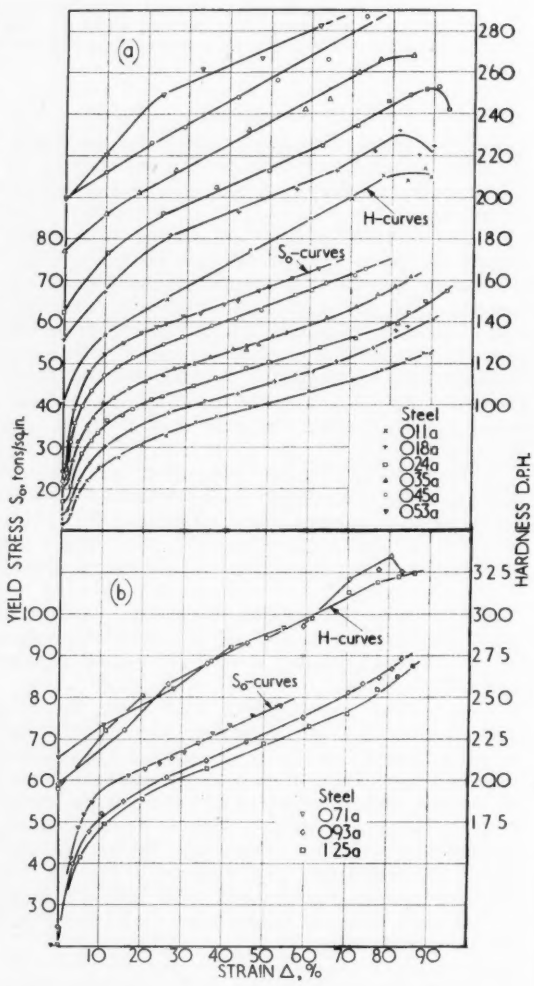


Fig. 2—Yield stress and hardness in compression of (*a*) low- and medium-carbon steels, (*b*) high-carbon steels

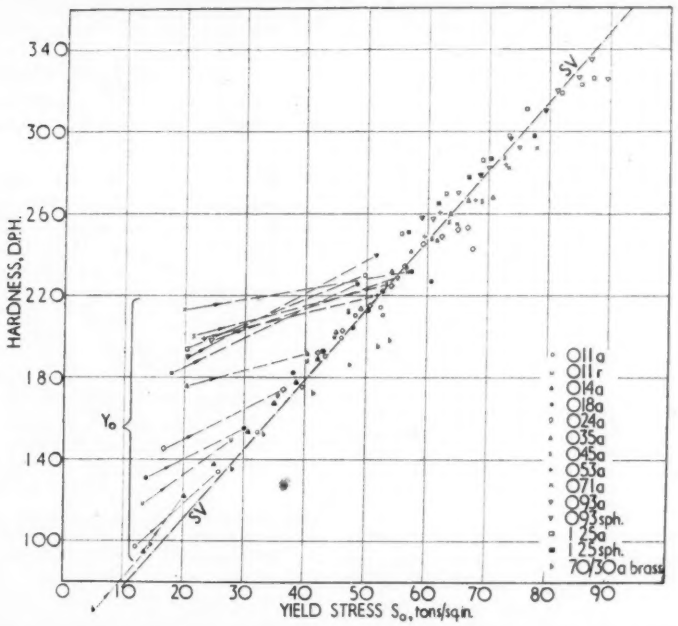


Fig. 3—Relation between yield stress in compression and Vickers hardness

cylinders being greased each time. Vickers hardness tests were made at various stages with a 20-kg. load (unless otherwise stated). Five equidistant impressions were made with a constant orientation across one diameter of the sample and five, at right angles to the former, across the opposite face, so that each experimental figure represents a mean value from ten readings. In order to obtain compression specimens which had received a comparatively small tensile overstrain, the tensile tests were interrupted at an early stage and suitable pieces were cut from the tested rods. The remainder were stretched till fracture, and because of some tapering it was possible to choose portions deformed to different extents for subsequent compression tests.

Only the ends of the compression cylinders were machined, and no surface hardening could be found. Their average diameter was calculated as a mean from six readings taken in the routine manner with a 25/0·01-mm. micrometer. Usually the 25-ton scale of the Amsler hydraulic machine was used for compression and the 10-ton range for tension. Autographic records were taken by means of a plain 6-in. extensometer clamped on the 12-in. tension specimens. These records were later recalculated in actual stress units, a few direct diameter measurements being used as a check.

The materials used were of commercial quality, and the carbon steels together with the marking used are listed in Table I. The suffix *r* denotes as-received, *a* fully annealed, *d* as-drawn (cold), *sph* spheroidized, *da* cold-drawn and later fully annealed.

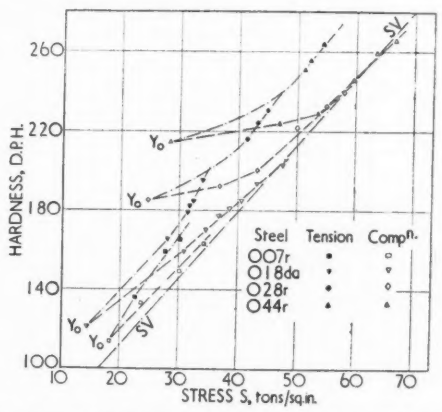


Fig. 4—Comparison of stress/hardness curves of carbon steels obtained from tension and compression tests

TEST RESULTS

Comparison of Compression and Tension

Results of a series of homogeneous compression tests performed by employing the refiguring method described in an earlier paper[32] are given in Fig. 2, and also in Fig. 3 plotted from the former. Figure 3 shows that after about 10% compression all the stress/hardness curves (*SH*) approach and follow fairly closely the ' best line ' *SV* which can be represented by the equation $H = 3{\cdot}4S_o + 44$. This line is used later as a first approximation to the *SH* relationship characteristic of compression.

The ' virgin ' tension and compression curves in Fig. 1 indicate that for equal linear strains the compression curves in steel always run above the respective tensile stress/strain curves. However, the hardness/strain curves (*H*-curves) behave in the opposite way, and the H_{ce}-curves are systematically below the H_{te}-curves (*see* Figs. from 5 onwards). These differ-

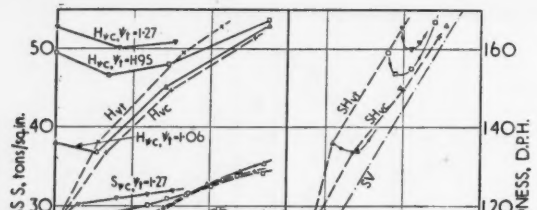


Fig. 5—Tension and compression tests on a 0·07% carbon steel (007*r*). (Note the decrease of hardness during compression following tension.) (*a*) Stress curves and hardness curves, (*b*) stress/hardness curves

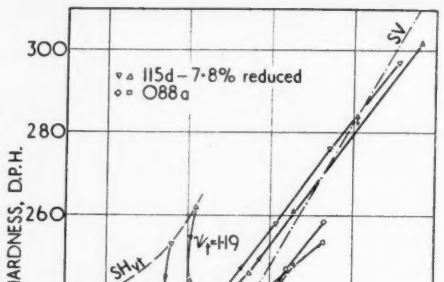


Fig. 7—Stress/hardness curves obtained from tension and from compression tests on 'virgin' and on overstrained steels with 0·88% and 1·15% of carbon

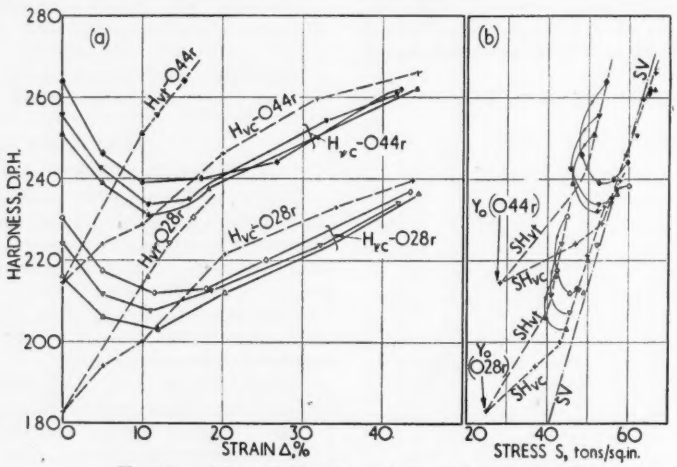
ences are still further accentuated when hardness is plotted against the actual stress, whether tensile or compressive as shown in Fig. 4. The discrepancy between the *T*- and *C*-curves is large in the harder steels 028 and 044, but fairly small, although definite and systematic, in the mild steels 007 and 018, which suggests that it is related to the increase of the *B*-effect with carbon (Fig. 1).

The difference between the work-hardening values in tension and in compression is probably even larger than can be detected by indentation hardness measurements since a *B*-effect may be acting when a cold-stretched metal is indented by the hardness tester.

Compression following Tension

Low-Carbon Steels—Results obtained with Armco iron, and steels 007*r*, 013*r*, 014*a*, and 018*da* were essentially similar and so only those for the steel 007*r* are reproduced (Fig. 5). Three compression specimens with initial tensile overstrains ψ_t equal to 1·06, 1·195, and 1·27 were selected corresponding to 5·7, 16·3, and 21·2% deformation respectively. The hardness-compression curves H_{vc} are unusual in that the hardness initially decreases, reaches a minimum, and later increases, so that after 16·3% tensile overstrain followed by 18% compression the specimen is not harder than after extension alone.

The shape of the *SH* (*i.e.*, stress/hardness) curves in Fig. 5*b* indicates that during reversed deformation the stress/hardness relationship characteristic of tension (SH_{vt}) is gradually replaced by that peculiar to compression, *viz.*, SH_{vc}, or (approximately) *SV* from Fig. 3.



The values of the initial tensile overstrains ψ_t for the various $H\psi c$ curves in (*a*) are as follows:

Curve	Δ	▽	◊	▲	▼	♦
ψ_t	1·12	1·115	1·195	1·11	1·135	1·18

Fig. 6—Tension and compression tests on steels with 0·28% and 0·44% of carbon. (*a*) Hardness/strain curves, (*b*) stress/hardness curves

Since the maximum drop of hardness observed was 9 points with steel 013*r* and 12 points with 018*da* as compared with only 6 points observed in Fig. 5, it might be expected that it would increase further with increasing carbon, and this is confirmed by Fig. 6.

Medium-Carbon Steels—There was a maximum softening of about 17 points with the 028*r*-steel and 25 points with the 044*r* accompanied by a very strong *B*-effect. The *S*-curves can be easily reproduced from those given in Figs. 6*a* and *b*.

High-Carbon Steels—Similar *SH* curves for 088*a* and 115*d* are given in Fig. 7. Steel 115*d* was stretched in the ' as drawn ' condition (silver steel, cold drawn 7·8%), but the compression curve S_{vc} was not taken. Under similar conditions, however, a steel 145*a* with over 1·4% C exhibited a hardness drop of only 16 points, *i.e.*, less than steels with intermediate carbon ranging from 0·44 to 1·15%. This may indicate that the *B*-effect is less in steels with high carbon content (over 1·2%) than in those containing 0·5–1·0%.

An apparently relevant observation has been made by Uéda[33] who found that the elastic after-effect behaved in an approximately similar manner, having a maximum in a eutectoid steel of about 0·9% C.

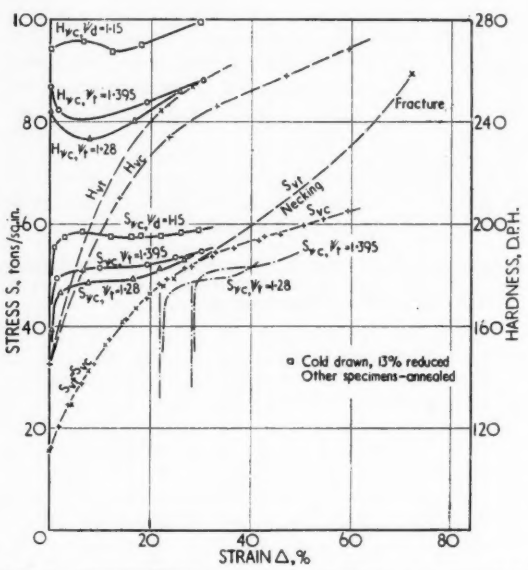


Fig. 8—Tension and compression tests on annealed and on overstrained Monel

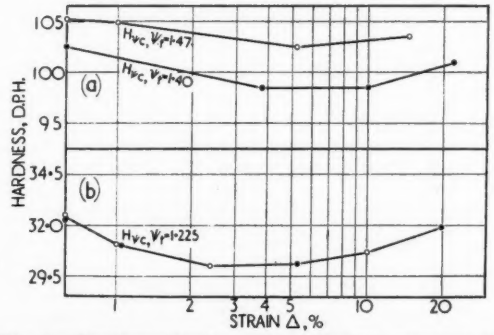


Fig. 9—Hardness/strain curves during compression following tension. (*a*) Copper cold-drawn and annealed at 600° C., (*b*) commercial aluminium

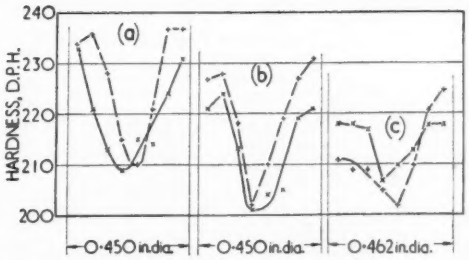


Fig. 10—Hardness distributions in cold-drawn phosphor-bronze rods (64·3% reduction in five drafts) (*a*) prior to, and (*b*) after heating at 200° C. for 8 hr. and (*c*) after subsequent 6% compression

Compression following Drawing and Torsion

Annealed rods of steels with 0·15 and 0·18% C were drawn in a series of approximately 10% successive drafts to about 50% reduction and tested in compression; the results closely resembled those obtained with stretched steels. Softening occurred also when a 0·09% C Bessemer steel and a 0·525% C open-hearth steel (053*a*) were compressed after torsion.

Experiments with Non-Ferrous Metals

The diagrams in Figs. 8 and 9 show that Monel, copper, and aluminium behave in the same way as steel. Equivalent results were obtained on compression of cold-drawn copper, phosphor bronze, 70/30 brass, and 80/20 copper–nickel.

Masing[24] suggested that it was possible to dispose of the *B*-effect by heating a metal to a low temperature. Such treatment should eliminate the residual stress[34] without affecting the hardness. To verify this, specimens cut from a cold-drawn phosphor-bronze rod and from a stretched 70/30-brass rod were heated for 8 hr. at 200° C. In both cases some softening occurred on heating, and additional softening after compression (*see* Figs. 10 and 11*b*). All three diagrams in Fig. 10 are similar to the internal stress distribution in drawn rods found by Heyn[23] and by Sachs.[35]

The changes of hardness values and of their distribution after heating or after axial compression correspond exactly to the change of residual stress across the section of a drawn rod observed by these authors, after similar treatments of their test pieces. These results seem to cast doubt on Masing's and Eichinger's[36] claims, implying that hardness values are independent of the residual stresses and consequently of the *B*-effect.

Low-Temperature Heat-Treatment

A number of samples overstrained by tension and by drawings were heated to 200, 250, and 400° C., and except for Armco iron, which softened on heating to 400° and later hardened during compression, all

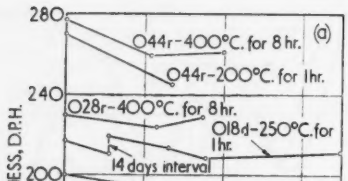


Fig. 11—Hardness/strain diagrams of stretched and of drawn specimens subjected to low-temperature heat-treatment and tested in compression. (*a*) Steel, (*b*) 70/30 brass

the other specimens behaved in a manner similar to those compressed immediately after stretching or drawing (Fig. 11). Thus even very drastic ageing treatment is not capable of eliminating the work-softening effect in steel.

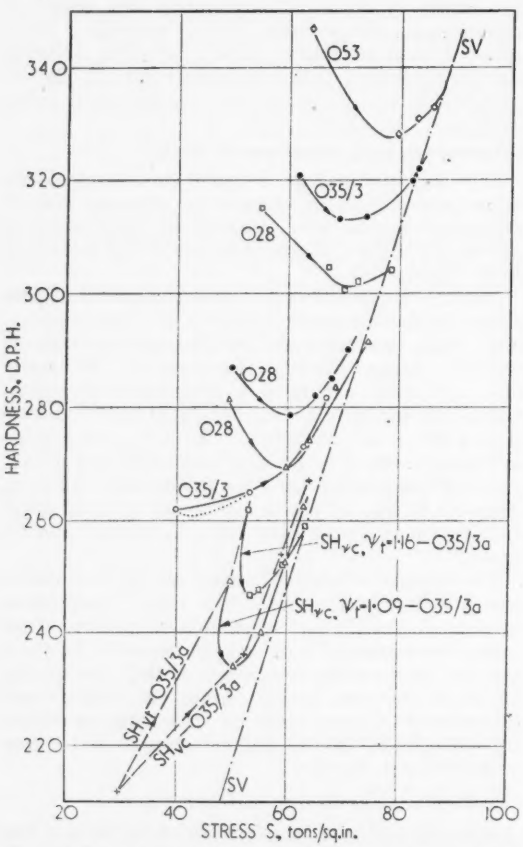


Fig. 12—Stress/hardness curves of two carbon steels and a nickel steel with 0·35% C and 3% Ni (035/3) heat-treated to different initial hardnesses

Experiments with Heat-treated Steels

Compression Tests—Carbon and low-alloy steels both in the quenched[37] and in the tempered condition contain considerable internal stresses and it is to be expected that they should behave like metals in which the internal stresses have been produced by cold work. Hence they should soften during cold-working, and this is confirmed by the results in Fig. 12.

Whenever the initial hardness exceeds about 280 DPH in the heat-treated materials the characteristic ' drop-over ' of the *SH* curves is apparent. Irrespective of initial hardness these curves (as shown in Fig. 12) converge to the ' basic ' *SV* line taken from Fig. 3.

Rolling and Drawing—Steel strips 0·040 in. thick, hardened and tempered to 350–500 DPH, were rolled in a series of very light passes on a small hand-driven mill with 2·5-in. rolls ; as seen in Fig. 13, a drop of hardness of up to 40–50 points was noted in some of the higher-carbon samples, and one of 12–22 points in steels with 0·25–0·5% C. O'Neill[19] stated that a sorbitic tyre steel with 0·61% C and initial hardness 314 DPH, exhibited an increase of hardness of only 7 points (to 321 DPH) after as much as 40% reduction by rolling. This is explained if one assumes that the above steel first slightly softened and began to work-harden at a later stage as in the samples of Fig. 13. The same explanation could account for the effects of cold work on the hardness of heat-treated steels as found by Armour,[21] Adam,[18] Goss and Brenner,[22] and Andrew and his associates[20] (*see* Fig. 14).

A MECHANICAL MODEL REPRODUCING STRESS/STRAIN AND ENERGY RELATIONS DURING REVERSED DEFORMATION

The behaviour of indentation hardness in the course of reversed deformation and its relation to the ' simple ' *B*-effect can be conveniently studied on a mechanical model (*see* Fig. 15).

It consists of the following elements (Fig. 15*a*) : (i) a ' soft ' spring K_1, one end of which is anchored at *W*, the other being attached to the slider *T* ; (ii) a slider *T*, pressed with a constant load *Q* against a rough base-plate *M*, the coefficient of friction between *T* and *M* being μ ; (iii) a ' hard ' spring K_2.

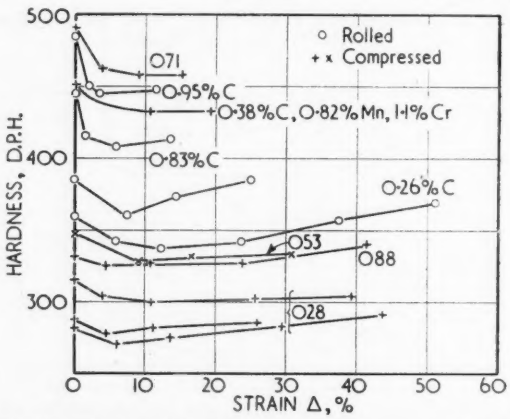


Fig. 13—Hardness/strain diagrams of compressed and of rolled carbon steels and a low-alloy steel, heat-treated to various tempers prior to cold working

with a very steep load-extension characteristic ; and, (iv), a dashpot D connected in parallel with K_2 and equipped with an adjustable valve V.

When an external force P is applied to the spring K_2 it begins to extend. However, this extension is not accompanied by a simultaneous movement of T as long as $P < \mu Q$. When P just exceeds μQ the slider T begins to move over M and there is correspondingly a sharp bend y_0 on the extension diagram S (Fig. 15*b*). The gradual slope of S after passing y_0 is caused by the soft spring K_1 which counteracts the further displacement of the slider T. If the slider is stopped at, say y_1 and the external load P is taken off, spring K_2 will contract by Δ_E, but the slider will not return to its original position because the tension in K_1 is less than μQ (this is an obvious limitation of the range within which the model serves its purpose). The extension from A to m_1 is therefore permanent and represents plastic deformation.

The point y_0 can be regarded as the virgin yield point of the ' material ' and $Y_0 = \mu Q$, as the original yield load. By stretching the ' material ' from its initial condition by the amount Am_1 the yield point has been raised to y_1 and the elastic range from Ay_0 to m_1y_1. As long as valve V is closed the gas locked in D will act merely as an additional elastic element and consequently no hysteresis loop will be formed. (It is assumed that there is no heat transfer through the walls of the dashpot, and also, that there is no clearance between the piston and the perfectly smooth walls.) When V is opened ventilation work will be expended on loading and unloading within the elastic range, and this irreversible work is demonstrated by

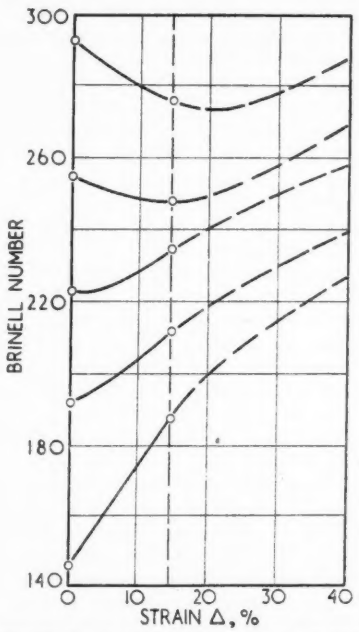


Fig. 14—Hardness of $\frac{11}{16}$-in. dia. rods of a 0·35% carbon steel after different heat-treatment and after a subsequent single 15% draft through a die in each case (Armour[21]). The broken lines represent plausible extensions of Armour's experimental results

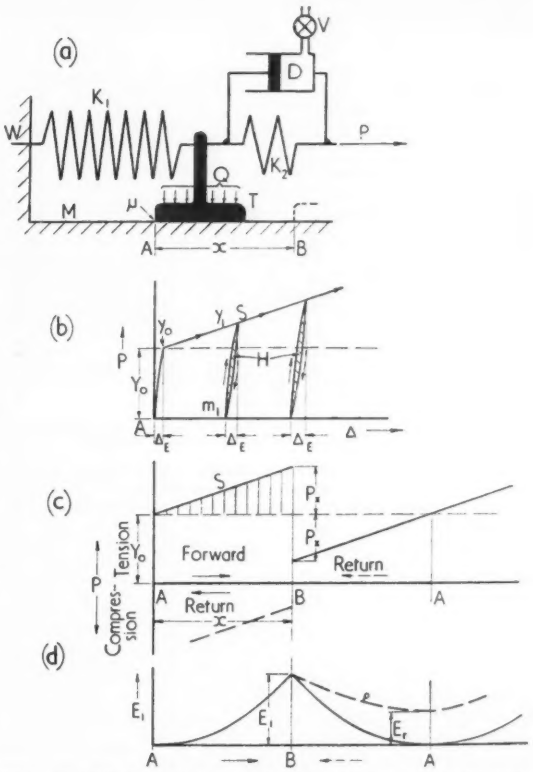
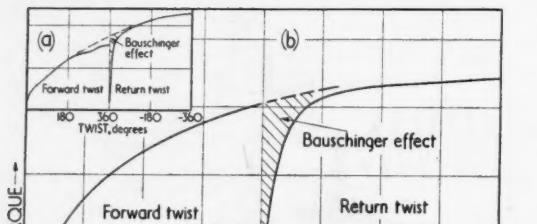


Fig. 15—Mechanical model capable of reproducing elasticity, damping (elastic hysteresis), work-hardening, and a *B*-effect during a single reversal of the direction of deformation. (Valid for $P<2\mu Q$.) (*a*) Layout, (*b*) extension diagram, (*c*) extension followed by compression, (*d*) energy diagram

closed hysteresis loops H, their length and width depending on the range of load applied and on the setting of V.

For the purpose of the present argument the elastic range is of little importance and the model may consist of spring K_1 and the slider T only. In such a case, in order to move T from A to B over a distance x an external force $P = Y_0 + P_x = \mu Q + k_1x$ is to be applied (k_1 is the spring constant of K_1 and it is equal to the slope of S) as is shown in Fig. 15*c*. To move the slider in the reverse direction, *i.e.*, from B to A, a reduced force $P = Y_0 - P_x = \mu Q - k_1x$ is required because the tension in K_1 ($= P_x$) acts so as to ease the movement of T in this direction. Hence, there is an abrupt drop of the actual ' yield load ' on reversal which is equivalent to a simple *B*-effect (*see* Fig. 1).

The internal energy of the system stored in spring K_1 is equal to the area of the shaded triangle in *c*, so that $E_i = x(P_x/2) = x(k_1x)/2 = k_1x^2/2$. It follows that E_i obeys a parabolic law (diagram *d*) and when the direction of the slider T is reversed E_i decreases smoothly and starts to increase only after passing the zero position. Work-hardening of metals is, of course, never fully reversible and the appropriate energy curve will never fall back to zero but will resemble



Curve E' shows number of freshly formed crystals after recrystallization
Curve E'' shows percentage extension under constant load

Fig. 16—*B*-effects and associated phenomena in reversed torsion tests on aluminium single crystals: (*a*) Sachs, 1926[2]; (*b*) Van Arkel and Van Bruggen, 1933[5]

rather the dashed curve p drawn on the same diagram. E_r is the residual, irreversible portion of E_i which cannot be ' extracted ' from the system by mechanical means, such as reversal of the direction of deformation.

It is evident that the energy curves just described are similar in form to the hardness curves previously described. Equal properties are exhibited by the curves E' and E'' (if $1/E''$ is taken as a basis of comparison) in Fig. 16, as well as those obtained by Swift[38] in reversed torsion tests performed on a wide variety of ferrous and non-ferrous metals.

The parallelism between this model and experimental findings led the author to the conclusion that there must be a close relation between indentation hardness and the amount of latent energy in a cold-worked or a heat-treated metal.

DISCUSSION OF RESULTS

The following interpretation of the experimental results is put forward :

(i) Strengthening of a metal either by cold-working or by quenching induces in it systems of internal stresses which differ according to the method of treatment applied.

(ii) The application of an external force, which tends to produce a system of internal stresses differing from that left after stage (i) causes, in the first instance, a breakdown of the previous internal stress system. This breakdown is associated with a decrease of the internal energy of the deformed metal.

(iii) The decrease of internal (latent) energy is equivalent to ' work-softening ' of the metal as is demonstrated by the lowered indentation hardness, raised recrystallization temperature,[1–5] and elongation value[5, 31, 39, 40] as well as by relevant changes in X-ray patterns.[1, 2, 25]

(iv) At the same time the excess energy which is released reduces the amount of deformation energy which would otherwise have to be supplied from the outside in order to start and maintain plastic flow. For this reason the stress values at the beginning of reverse deformation are lowered (simple *B*-effect), as shown in Fig. 15.

The *B*-effect exhibited by freshly drawn wires[41] and rods, and cold-rolled strip when tested in any direction is explained by (ii). This effect is demonstrated by a smoothly rounded, gradual transition from the elastic or plastic-elastic, to the plastic state and is most pronounced when caused by axial compression, opposite to the direction of elongation in drawing or rolling.[42]

This reasoning can be extended to apply to heat-treated steels as follows :

(v) Cold-working tends to produce in a steel a system of internal stress more or less different from that caused by a quenching treatment. Therefore, cold-working after quenching results in an equivalent to a simple *B*-effect, this being demonstrated by the low stress value at which such steels exhibit a permanent set.

(vi) Tempering has the effect of raising the elastic limit and yield (proof) stress, which have been lowered by previous cold-deformation or quenching.[37] This led to the widespread belief that the *B*-effect could be eliminated by this method, or even, in mild steel, by natural ageing.[24, 43, 44] The results given in Figs. 12 and 13 show that work-softening is not eliminated in this way. Other experiments (to be reported later) prove conclusively that the *B*-effect also is not eliminated by ageing.

Incidentally, for equal linear deformation, extension causes more work-hardening than compression both in steels and in cubic non-ferrous metals.

APPLICATION TO ROLLING, DEEP DRAWING, AND FATIGUE

The Effect of Straight-, Cross-, and Reversed-Rolling on Properties of Sheet Metal

Feitknecht[13] found that the cross-rolled sheets of aluminium always recrystallized at a higher temperature than those rolled in one direction, showing that there was less work-hardening in the first case. He also suggested that indentation hardness could be taken as a measure of ' real deformation ' (= amount of cold work received) of the metal and expected the cross-rolled sheets to be softer.

Experiments on similar lines were later carried out by Brick and Williamson[14] on copper sheets, and by Bowles and Boas[16] on copper, silver, and two qualities of aluminium ; the cross-rolled sheets were appreciably softer in each case.* It is also known that straight-rolled sheets contain more residual stress than when the direction of rolling is altered after each pass.[15]

An examination of the shape of vertical lines scribed on the sides of rolled bars[45] or of vertical pins inserted into slabs[46] rolled in reversing mills indicates that the distortion caused in one pass is largely offset in the following, when the direction of rolling is reversed. In this way some of the work-hardening is cancelled out in the same way as in ordinary reversed deformation. The result is that the rate

* Bowles and Boas' Table IV in the Appendix to their paper is particularly instructive. These authors used ' compression rolling ' instead of cross-rolling, *i.e.*, the direction was different in each pass but was not varied systematically from pass to pass. It is clear that qualitatively both processes are equivalent.

of work-hardening in reversed- and cross-rolling is reduced.

Brick and Williamson[14] noted that the effect of direction of rolling was appreciable with small, 4-in. rolls, but that it disappeared when large 14-in. rolls were employed. This was because the distortion of the original vertical planes in a rolled strip is negligible when the ratio of roll diameter to strip thickness (D/h) has a high value (nearly homogeneous compression).

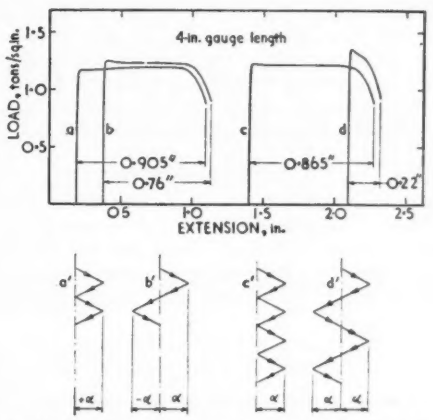
Hence the old claim that reversing small-roll mills, with relatively low D/h ratio, result in less work-hardening for equal reductions than conventional mills, although certainly exaggerated, may have contained some truth.

Reversed Deep Drawing

In conventional, direct drawing all the operations are carried out in the same direction, whereas in the reversed method the preformed cup is turned upside down and drawn inside out. The reverse process makes deeper draws possible and so reduces the number of operations required.[11–12] In addition, the residual stresses set up in the pressing are less, and the product is relatively immune against cracking caused by age-hardening.[10] A *B*-effect is active in both methods of deep drawing,[47] but its influence on the properties of the metal during and after working does not seem to be sufficiently explained in order to account for these striking differences.

Morgan's report[10] is the only source containing systematic experimental data on reversed deep-drawing known to the present author. He shows that direct redrawing involves two right-angular bends of the sheet in opposite directions, first over the edge of the blank-holder and later over the edge of the die, followed by straightening out. The reverse method involves also two bends of the same magnitude but in one direction only, the maximum amplitude being here 90° compared with 180° in the direct method.

This reverse bending results not only in a cumulative work-hardening effect but also in a progressive deterioration of the drawn metal indicated by its decreasing ductility. Experiments indicate that the loss of ductility during repeated reversed deformation depends primarily not on the total plastic strain (assumed additive) but rather on the amplitude of the strain applied, considering tension positive and compression negative. Consequently, the conditions closely resemble those encountered in fatigue tests where metals are able to endure a greater number of loading cycles when the applied range of stress is from 0 to $+S$, than when the range is from $-S$ to $+S$. Morgan has proved this damaging effect of alternate bending on ductility with two qualities of mild steel (Morgan's Fig. 5, also Tables V and VII). A spectacular, though indirect proof of the above statement is provided by the two pairs of autographic records reproduced in Fig. 17. The range of uniform extension in *a* and *c* in Fig. 17 is much broader than in *b* and particularly than in *d*, and this indicates the probable reason for the more uniform thickness of the walls in pressings produced by the reverse method. As there is less thinning near the bottom of the cup the necessity for using a slightly larger blank in reversed drawing[11] becomes obvious.



α = 450° (1¼ turns), (+) clockwise twisted, (−) counter-clockwise twisted
For *a'* and *b'*, Σα = 1800° and for *c'* and *d'*, Σα = 3600°

Fig. 17—Load-extension records of 0·25-in. wires over-strained by reversed torsion. Diagrams *a'*–*d'* show the twisting schedule employed in each case: 0·08% C steel wire, air-cooled from 930° C. (in vacuum)

Work-softening is effective only over a limited range of deformation, the minimum hardness value in the present experiments being reached in mild steel after about 5 to 10% compression following tension. From 0 to approximately 8% repeated reversed deformation results in a very low rate of progressive damage to the deformed material (mild steel), because of work-softening on each reversal, and is therefore relatively safe under repeated drawing operations.

The lesser degree of work-hardening caused by reversed drawing results in a lower yield point which, in turn, limits the residual stress. Because of the lower residual ductility in pressings produced by the direct method the effects of ageing will be more dangerous than in reversed redrawing.

The Effect of Repeated Alternating Stress (Fatigue Testing) on the Properties of Heat-Treated Steels

During fatigue testing metals become cold-worked, their tensile strength and hardness rise, and their ductility decreases. These changes are very pronounced in annealed and normalized steels, the increase of tensile strength being up to 15 to 20%. However, the effect of even a prolonged 'understressing' treatment on the same steels in a sorbitic condition is negligible, and the figures of the increase of tensile strength quoted (1–3%) lie within the possible limits of experimental errors.[48] It is suggested that the previous general explanation is also applicable in this case.

CONCLUSIONS

Evidence has been presented to show that the 'simple' *B*-effect is accompanied by mechanical softening of cold-worked metal.

A simplified mechanical model that imitates the stress and internal energy changes occurring in a metal during large reversed deformation illustrates

the *B*-effect and accompanying softening of the metal.

The low rate of work-hardening during reversed-rolling or cross-rolling of sheets, reversed deep drawing, and during rolling and drawing of hardened and tempered steels can be explained by this analysis of the present experimental results.

Acknowledgments

The author wishes to thank the Council of The Iron and Steel Institute for a second award from the Andrew Carnegie Research Fund and the University College of Swansea for hospitality and a supplementary grant ; Professor H. O'Neill for valuable advice and encouragement ; Professor L. G. Kastner for facilities in the Engineering Department, and Mr. P. A. Cunningham for assistance ; Mr. J. S. Caswell and Mr. D. W. Hopkins for discussion and for correction of the text. Samples were presented by Messrs. R. Thomas and Baldwins, Ltd., The Brown-Firth Research Laboratories, Colvilles, Ltd., Thomas Bolton and Sons, Ltd., The Mond Nickel Co., J. B. and S. Lees, Ltd., Sanderson Bros. and Newbould, Ltd., and the Whitehead Iron and Steel Co., Ltd., to whom the author's thanks are given.

The interest and assistance of the late Mr. Roosevelt Griffiths is acknowledged with gratitude and affection.

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Hot-Cracking of Austenitic Welds

WITH SPECIAL REFERENCE TO 18/13/1 Cr–Ni–Nb ALLOY

By E. C. Rollason, Ph.D., M.Sc., F.I.M., and M. C. T. Bystram, B.A.

SYNOPSIS

A study has been made of the influence of grain size, strain, and heterogeneity (both coring and non-metallic forms), intermetallic compounds, and the presence of ferrite and trace elements on the hot-cracking of austenitic Ni–Cr alloys. Hot bend and hot tensile tests have indicated that micro-cracks in the austenitic alloys occur at temperatures above 1250° C.

Contributory factors are internal stress, heterogeneity of structure, and high sulphur content. The addition of 1–1½% of niobium, together with more than 0·09% of carbon has a beneficial effect when silicon is low (0·2–0·4%). Higher silicon contents are detrimental.

To explain micro-cracking a hypothesis is suggested based on the fit of alloying elements in the transition lattice of the boundary ; the beneficial effect of the presence of ferrite is also explained.

For a number of years it has been known that welds of austenitic alloys ranging from 12/12 to 80/20 nickel–chromium were highly susceptible to cracking at elevated temperatures during the welding operation.

Under conditions of high restraint, cracks occur readily in the throat of the weld, which remains hot longest, and which is subjected to contraction stress. The 25/20 alloy was not, therefore, used for making joints in heavy armour during the last war, but it was used effectively as a buttering or interlayer on the joint surfaces, under which conditions the restraint is relatively low. Even under conditions of low restraint some high-nickel alloys are susceptible to cracks around a few crystal boundaries (micro-cracking).

The need to fabricate large gas-turbine rotors by welding together small forgings, particularly of 18/13/1 Nb alloy, has again focused attention on this problem. A fully austenitic structure is desirable to minimize the formation of the brittle sigma-phase under heat-treatment or service conditions. The use of carefully designed electrode coatings has minimized the risk of major hot cracks in 18/13/1 alloys, but the elimination of all micro-cracking has proved more difficult to achieve. The most satisfactory way of avoiding hot-cracking in 18/10 welds is by the addition of molybdenum or other ferrite-forming element in sufficient quantity to produce at least 5% of ferrite in the structure.

Austenitic plate is not as susceptible to cracking as weld metal of similar composition, indicating that segregations in a cast structure influence cracking. Films of sulphide, silicate,[1] and carbides may have an effect, whilst metallic compounds may also be important. A niobium content exceeding four times the silicon content prevents cracking in 80/20 deposits.[2]

The present work was carried out on various weld deposits, whose analyses are given in Table I.

EXPERIMENTAL WORK

Crack Tests

The main tests used for revealing crack susceptibility are :

(i) The Murex hot-crack machine,[3] in which a single bead is strained during deposition by an external force. Controllable strains are available and cracks are opened, making etching unnecessary (*see* Fig. 2*a*).

At speed 1, 50% cracking would indicate cracking in service even under low restraint. Slight cracking at speed 4 indicates high resistance to hot-cracking, and the weld is likely to be satisfactory in the majority of service conditions

(ii) The circular multi-run pad test, in which weld metal deposits on the end of a steel bar, 2 in. dia. × 4 in. long. Normal contraction stresses and strains are involved, since little warping of the bar occurs. To reveal the cracks, the weld metal is turned in a lathe to the centre of the beads, and the surface is polished and etched as shown in Fig. 2*b*

(iii) Longitudinal pad test, in which pads are built up on flat bars, sectioned longitudinally, and etched. Restraint is lower than in (ii), the warping of the bar being analogous to a spring. Later beads can alter the stress distribution in the earlier runs and thus give rise to strain. The stress can also be accentuated by depositing beads on the face of the plate opposite the test welds.

Type of Crack

The use of both Murex- and pad-cracking tests is justified by results shown in Table II. Welds *A2*, *AS*, and *SI* contain ferrite in the structure and reveal no micro-cracks in the pad tests, yet the Murex test indicates that welds *AS* (sulphur containing) and *SI* (high silicon) would crack in the throat when making a fillet joint, whilst *A2* would be satisfactory under conditions of severe restraint.

The fully austenitic welds *T* and 12 show widely different crack propensities in the Murex test. In spite of a fairly good crack resistance of a single bead at speed 4, weld 12 shows a number of micro-cracks in a multi-run pad test. Further examination of sections of the single-bead Murex test specimens of steel 12 failed to reveal micro-cracks ; also the final beads on the pads have no cracks. This appears to indicate that reheating by subsequent beads has some influence on the formation of micro-cracks in this weld metal.

For convenience the two forms of hot-cracking may be designated ' single-bead hot cracks ' and ' multi-

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Table I

ANALYSES OF WELD DEPOSITS TESTED

Code	Cr	Ni	Mn	C	Nb	Si	Mo
1	18·9	12·5	1·1	0·07	0·76	0·24	Nil
2	18·6	12·5	1·1	0·08	0·86	0·26	Nil
3	18·9	12·5	1·1	0·08	0·86	0·26	Nil
4	18·9	12·4	1·1	0·085	0·92	0·37	Nil
5	18·6	12·6	1·1	0·08	0·84	0·22	Nil
6	19·0	12·6	1·1	0·07	0·72	0·27	Nil
7	19·0	12·5	1·2	0·085	0·99	0·26	Nil
8	18·3	13·0	0·92	0·065	0·63	0·26	Nil
9	18·3	12·9	0·96	0·06	0·44	0·15	Nil
10	18·9	12·8	1·3	0·105	0·98	0·31	Nil
11	19·0	12·6	1·2	0·10	1·1	0·33	Nil
12	19·0	12·7	1·2	0·094	0·74	0·17	Nil
13	18·5	12·8	1·2	0·108	1·04	0·22	Nil
14	18·5	12·8	1·2	0·14	1·45	0·28	Nil
15	18·5	12·7	1·2	0·132	1·39	0·28	Nil
16	18·6	12·8	1·2	0·104	0·97	0·28	Nil
17	18·0	12·9	1·1	0·07	...	0·30	Nil
18	18·1	13·0	...	0·11	...	0·30	Nil
19	18·0	12·9	2·9	0·12	1·17	1·06	Nil
20	17·9	13·0	1·1	0·08	1·1	1·0	Nil
A2	20·0	9·5	1·5	0·1	0·8	0·5	3·5
AS	20·0	9·5	1·5	0·1	0·8	0·8	3·5
T	18·5	13·0	1·9	0·09	0·9	0·6	...
SI	18·7	12·7	1·3	0·08	1·3	3·8	...
12	19·0	12·6	1·2	0·094	1·1	0·33	...
TS	18·6	12·8	2·05	0·11	0·85	0·48	...
X	17·2	12·6	1·1	0·16	1·2	0·5	Nil
Y	19·4	9·4	0·5	0·08	1·0	0·72	Nil
A	19·5	9·2	1·8	0·08	Nil	0·8	3·5
M	19·0	9·1	1·3	0·07	0·8	0·8	3·1
C	18·5	13·0	1·9	0·09	0·9	0·6	Nil

bead micro-cracks,' although the two forms are related.

FACTORS AFFECTING EMBRITTLEMENT

The various factors affecting hot-cracking of austenitic welds, summarized in Fig. 1, are discussed in detail.

Grain Size

The micro-cracks are mainly intercrystalline, but a few occur through interdendritic segregations. The extent of boundary area available to accommodate contraction strain is therefore important, and small grain size is desirable. The investigation of weld deposits is difficult, since it is often impossible to change one factor alone, and grain size, in particular, can be controlled only to a limited extent. The orientation of columnar crystals is propagated from one bead to subsequent beads producing very long crystals. The presence of ferrite in the structure, however, produces much smaller crystals. Interpass peening may help to break up the continuity of columnar crystals. The improvement obtained by interpass homogenization at 1100° C. (*see* p. 349) indicates indirectly that the grain size is not the main factor in promoting cracks.

Table II

RESULTS OF HOT CRACK TESTS

Code	Circular Multi-Run Pad Test (micro-fissuring)	Murex Hot-Cracking Machine Test Crack Length, %	
		Speed 1	Speed 4
A2	No cracks	0	0
AS	No cracks	100	100
T	Excessive cracks (100%)	100	100
SI	No cracks	100	100
12	Few cracks (3%)	10	50
TS	Many cracks (80%)	100	100

Strain and Heterogeneity of Structures

Plate material of 18/13/1 composition is not readily cracked by the deposition of weld metal although splash droplets have been found to cause star cracks in the plate, as shown in Fig. 3. Such small cracked areas have been raised to a very high temperature and plastically deformed. Subsequent contraction under the rigid restraint of the surrounding plate has

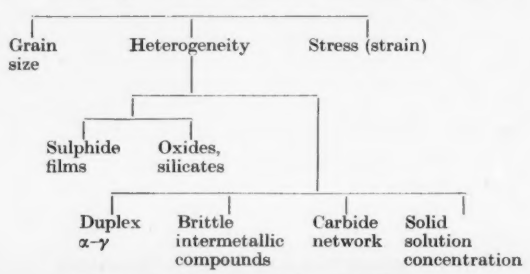


Fig. 1—Factors affecting embrittlement

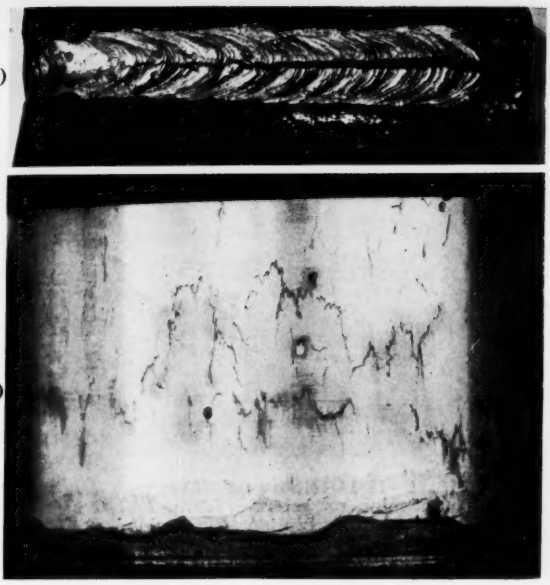


Fig. 2—Typical cracks in 18/13/1Nb welds : (*a*) On Murex crack machine ; (*b*) by multi-run pad tests. Etched in aqua-regia

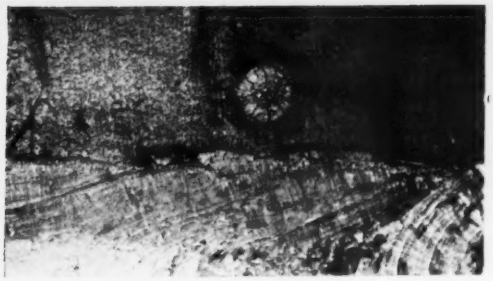


Fig. 3—Star cracks in plate of 18/13/1Nb alloy under splash droplets, which have been removed. Surface etched

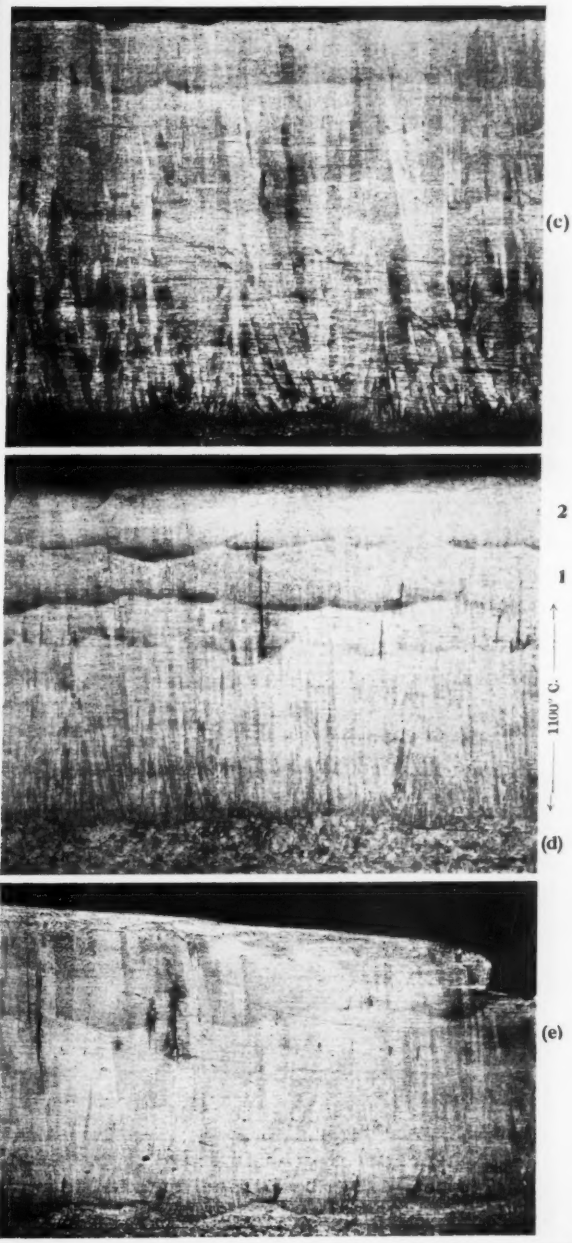
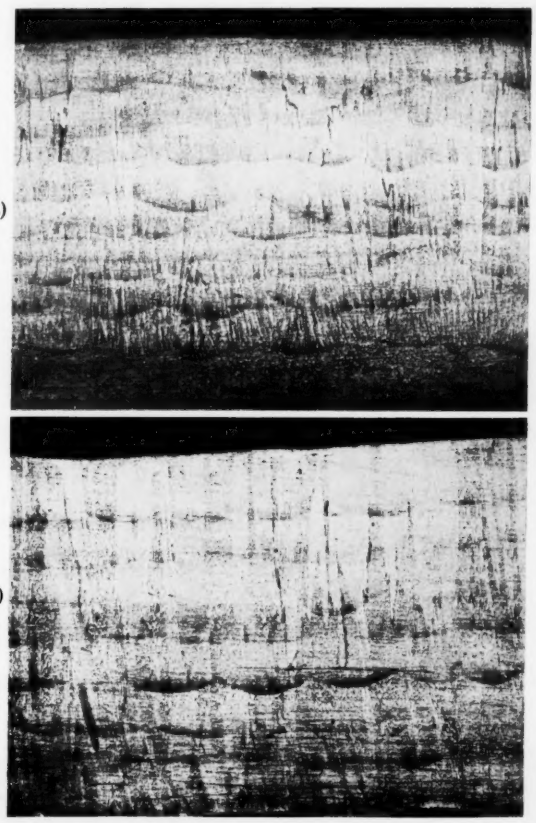


Fig. 4—Longitudinal pads of 18/13 weld metal : (*a*) As-welded 18/13/1Nb ; (*b*) 18/13/1Nb interpass stress-relieved at 800°C. ; (*c*) 18/13/1Nb homogenized by interpass annealing, 2 hr. at 1100°C. ; (*d*) as (*c*) but stressed by deposit of beads on opposite side of plate: 2 normal beads applied on homogenized layer ; (*e*) 18/13 weld metal, prepared as (*d*) × 3



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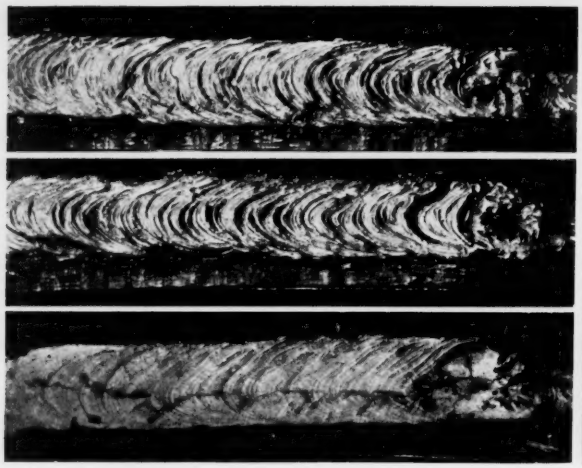

Fig. 5—'T' fillet tests on 18/13/1Nb weld metal : (*a*) Weld *T* (0·02% of S) ; (*b*) weld *TS* (0.28% of S) ; (*c*) weld 20 (low sulphur + 0.8% of Si)

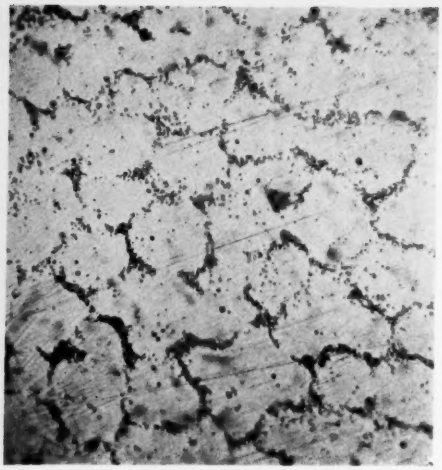

Fig. 6—18/13/1Nb weld (*X*) with low tendency to micro-cracking, showing granular distribution of carbide × 750

(a) (b) (c)

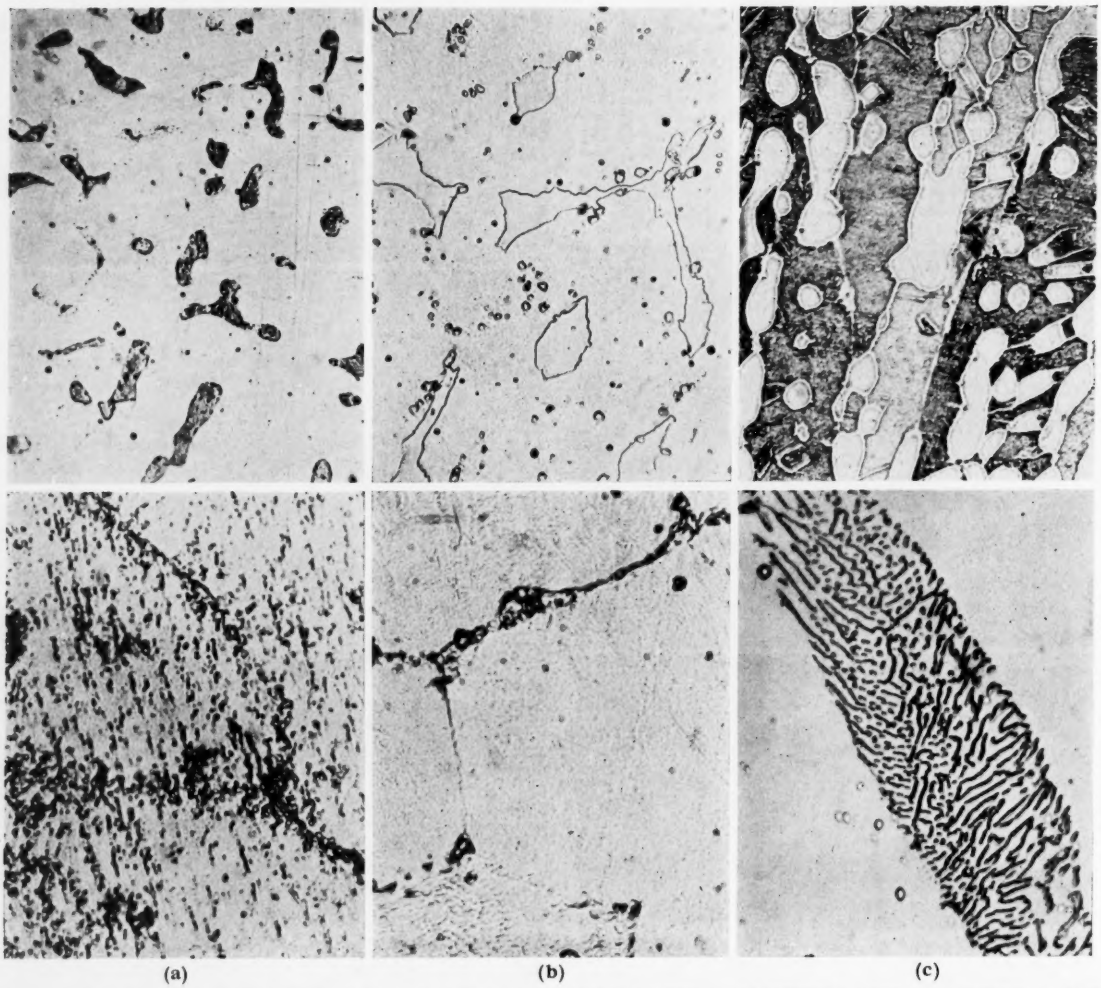

Fig. 7 (upper)—19/9/1Nb weld metal, quenched from : (*a*) 1100°C. (× 750) ; (*b*) 1300°C. (× 750) ; (*c*) 1400°C. (× 100)
Fig. 8 (lower)—18/13/1Nb weld metal, quenched from : (*a*) 1100°C. ; (*b*) 1300°C. ; (*c*) 1400°C. × 1500

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XUM

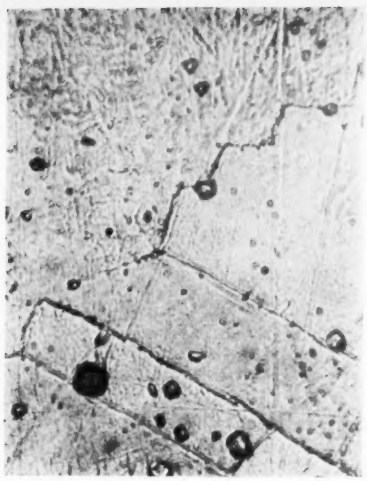
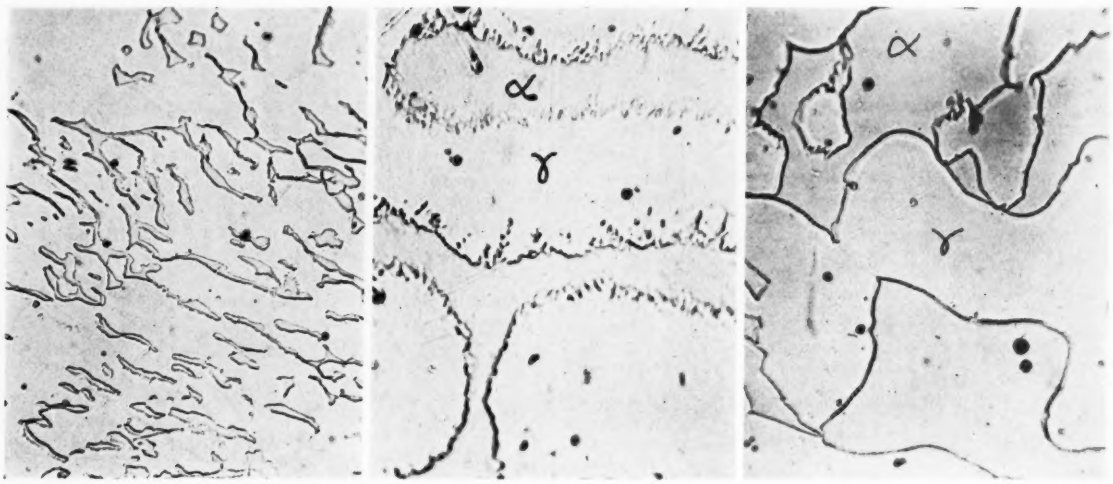


Fig. 9—18/13 weld, quenched from 1400°C. × 1500



(a) (b) (c)

Fig. 10—19/9/3 Mo weld metal, quenched from : (*a*) 1100°C. ; (*b*) 1300°C. ; (c) 1400°C. × 750

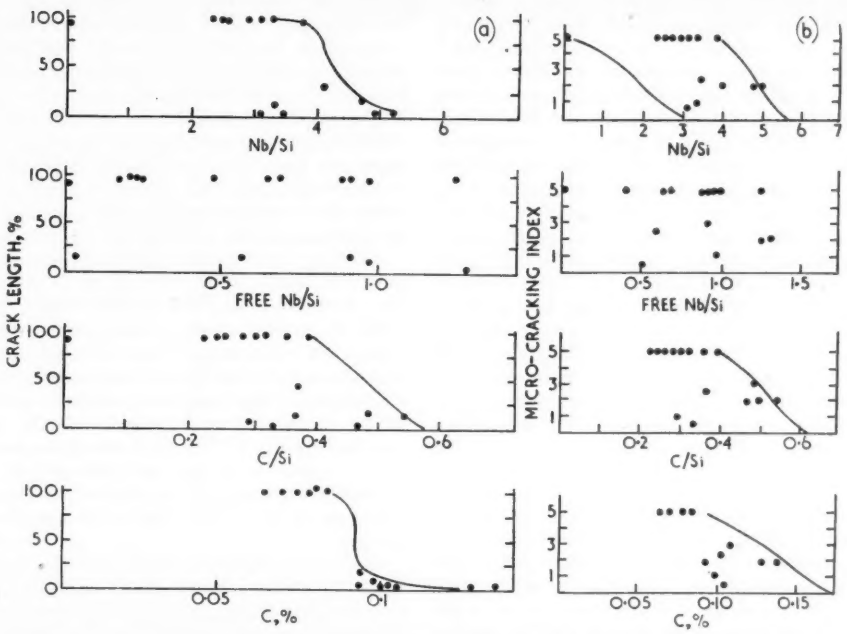


Fig. 11—Effect of composition of 18/13/1 alloys on : (*a*) Hot-cracking in the Murex machine, (*b*) multibead micro-cracking (Index: 5 very bad cracking, 3 medium cracking, 1 few cracks)

caused cracks. Multi-bead weld metal, however, exhibits considerable cracking and the effect of segregation, which occurs in cast structures, and the effect of internal tension stresses built up in multi-runs have been examined. A number of pads, up to eight beads high, were deposited on ½-in. plate from one batch of 18/13/1 electrodes and were examined for micro-cracks. The welds had the composition *T* (*see* Table I).

As-Welded Specimens—No cracks were found in the last run except at the junction with the lower bead; other beads were cracked (*see* Fig. 4*a*).

Stress Relieved Specimens—After each bead was deposited the pad was annealed at 800° C. for 1 hr., and furnace-cooled to release tension stresses set up by thermal contraction of the bead; a section is shown in Fig. 4*b*.

The cracking was similar to that in a pad without heat-treatment, indicating that micro-cracks result from low integrated internal stress, and that low thermal strains are sufficient to produce the cracks on a few boundaries. As cracking is no worse than in the as-welded state it can also be concluded that the heating at 800° C. has not intensified cracking by the formation of the sigma-phase.

Homogenized Specimens—After each bead was deposited, the pad was annealed at 1100° C. for 2 hr. to reduce coring by diffusion. This was in addition to relieving stresses in the weld. The amount of cracking was reduced considerably (1% of the un-annealed sample), showing that segregation phenomena have an important effect on cracking (*cf.* Figs. 4*b* and *c*).

Stressed Homogenized Specimens—Since treatment of each bead at 1100° C. for 2 hr. reduces internal stress to a low level, a pad, in which each bead was annealed at 1100° C., was stressed by depositing crack-resistant austenitic beads on the opposite side of the plate to reverse the warping of the plate and to induce tension stresses in the 18/13/1 deposit. Two beads of 18/13/1 metal were then deposited on the homogenized weld. A similar experiment was made with niobium-free 18/13 metal. As shown in Fig. 4*d*, as many cracks occurred in the non-heat-treated deposits (1 and 2) as in the top homogenized bead. The cracks have a tendency to spread into the top bead 2, showing that the external stresses have produced increased strain relative to the normal contraction present in the unstressed homogenized specimens. This strain was sufficient to produce cracks.

A similar experiment was made with a niobium-free 18/13 weld (No. 17, Table II) shown in Fig. 4*e*; the crack density and length in the homogeneous layer were greater than for 18/13/1 Nb. The fact that cracks are limited to a shallow depth in the top homogenized bead in Figs. 4*d* and *e* indicates that the cracking phenomenon occurs at a relatively high temperature (*e.g.*, above 1200° C.).

A few cracks lie in an arc below the crater shown in Fig. 4*e*. It might be inferred, therefore, that expansion and plastic flow of the lower bead below the crater is followed by contraction as the arc travels forward. If this contraction coincides with the incidence of weak intercrystalline film, cracks are more likely to occur than is plastic flow.

Non-Metallic Segregations

Under this heading may be considered oxides, silicates, and sulphides. That cracking results from intergranular oxidation seems to be incompatible with the mechanism of formation of the fissures. The improvement that results from homogenization treatment discussed above excludes oxides and silicates as major factors in promoting fissuring, since their diffusion rates are so low.

Sulphides, however, are known to be a major cause of hot-cracking in mild steels, and to test the effect of sulphur in austenitic steels, sulphur was added to

XUM

an 18/9/3 Mo steel (*AS*, Table I) containing ferrite in the structure, and to an austenitic 18/13/1 Nb steel.

Results for *AS* in Table II show that 0·39% of S drastically increased hot-cracking in the Murex test, but failed to produce micro-cracking in a pad test. In the 18/13/1 steel no increase in micro-cracking occurred. In both tests, however, the manganese content exceeded 1·5% and much manganese sulphide would therefore have been formed. A sulphur print from the duplex deposit, richer in sulphur, was paler than that from the high sulphur 18/13/1 alloy, possibly indicating that greater segregation of sulphides occurred in the latter.

For the 18/13/1 weld metal, Fig. 5 shows 'T' fillet tests on $\frac{3}{16}$-in. 18/8 plate. The specimens with low sulphur content (Fig. 5*a*) and with 0·28% of sulphur (Fig. 5*b*) have no cracks, yet the specimens with low sulphur content and a higher silicon content (1·0%) cracked. Thus, although sulphur increases hot-shortness, small additions of silicon can have a greater effect.

Intermetallic Compounds

The important influence of silicon focuses attention on possible intermetallic compounds that may form in the alloys. Analyses of many austenitic welds have shown an interrelation between C, Nb, and Si. In Fig. 11 the ratios of elements are plotted against the results of hot-cracking tests on 20 welds, whose analyses are included in Table I. Niobium was estimated by Cunningham's method.[4]

The ratio of free Nb/Si appears to have no direct connection with hot-cracking. An improvement in cracking occurs as the Nb/Si ratio increases, and as the C/Si ratio exceeds 0·5. Carbon contents exceeding about 0·08% have a pronounced effect. There is little evidence that a niobium-containing compound causes cracking, particularly as plain 18/13 metal also cracks.

The omission of niobium in weld 18, even with a high carbon content, increases cracking, indicating that a high carbon content is not in itself the only reason for improvement in hot-cracking. Weld 19 indicates that even when Nb and C are present in suitable amounts (*cf.* weld 13), the presence of 1·17% of Si is sufficient to increase hot-cracking.

This adverse influence of Si is also reflected in alloys containing up to 3·8% of Si (*SI*, Table I) even although this alloy contains 25% of ferrite. This amount of ferrite, obtained by the addition of other ferritizers (*e.g.*, Mo), gives a weld completely resistant to cracking both in the Murex test and in multi-run pad tests.

Welds having a low tendency to micro-cracking exhibited a carbide distribution which was sub-divided and granular. Figure 6 shows this for weld *X*.

In welds that cracked badly the carbide was in strings (*see* Fig. 8*a*). It is not thought, however, that carbide films themselves are a major factor in causing cracks, although dispersed carbides may mean that solidification and subsequent changes in the solid state are such that segregation effects are reduced. Improvement in crack resistance is therefore related to greater homogenization, which is shown to occur by heat-treatment at 1100° C. (*see* Fig. 4*c*).

Another intermetallic compound likely to cause embrittlement in austenitic steels is the sigma-phase. The formation of this phase occurs below about 1000° C., and can form rapidly when beads of some welds are reheated. Under critical conditions embrittlement of multi-beads can occur and contraction or warping of the specimen can cause cracks. Duplex alloys containing molybdenum, silicon, and niobium are most prone to this phenomenon. Large amounts of ferritizers such as molybdenum or silicon can therefore improve hot-cracking of as-deposited beads, but can cause cracks under certain reheating conditions.

Hot Bend Tests—To find whether regions of low ductility existed below 1150° C., hot bend tests on $\frac{3}{8}$-in. × $\frac{1}{2}$-in. specimens, over a radius equal to the thickness, were made after soaking the specimens for 20 min. in a jig. The analyses of the welds *A*, *M*, and *C*, are given in Table I. Curve *A* in Fig. 12 shows that 3·5% of Mo in 19/9 alloy caused no loss in ductility with the short-time heating. The addition of niobium as well as molybdenum causes a decrease in ductility at 800–1000° C. (curve *M*). Curve *C*, for 18/13/1 Nb, shows no such drop in ductility if existing micro-cracks are ignored. These cracks open up but do not propagate.

Hot Tensile Tests—Because 18/13/1 Nb alloys showed no appreciable drop in ductility up to 1100° C. the testing temperature was extended up to 1400° C. by carrying out tensile tests on samples *T* and *Y*, raised to the given temperature in a few seconds by electric resistance heating. The load was applied rapidly by releasing a cam and the reduction in area was taken as a criterion of ductility. The changes in ductility with temperature are shown in Fig. 13. The duplex 19/9/1 Nb weld lost its ductility at about 1390° C., whilst in 18/13/1 weld metal the change occurred at 1320° C. The corresponding temperatures for wrought material were about 50–100° C. higher than those for the corresponding weld

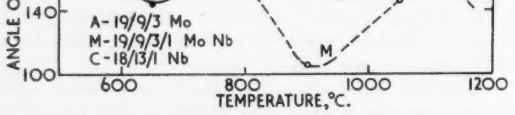


Fig. 12—Effect of niobium and molybdenum on the ductility of austenitic welds

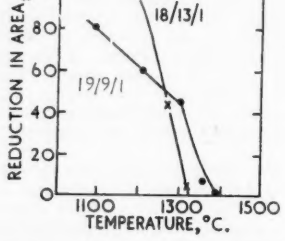


Fig. 13—Hot rupture tests on duplex 19/9/1 Nb weld and on austenitic 18/13/1 Nb weld

metal, although this result appears to vary with different manufacturers' wire. For example, one 18·2/8·6/0·84 Nb wire with 0·05% of C failed at 1450° C., whilst the 18/13/1 wire with 0·06% of C failed at 1380° C. A wire with 0·1% of C failed at 1410° C. This effect of carbon is in agreement with weld cracking characteristics. Before becoming ductile an 18/13/1 Nb weld has to cool through a greater range of temperature, and consequently has to accommodate more contraction than a 19/9 weld. There is thus more opportunity for hot-tearing to take place in segregated regions.

MICROSTRUCTURE

Duplex Ferrite–Austenite (19/9/1 *weld*)—Since the different crack propensities of duplex and single-phase alloys appear to be largely associated with changes in ductility above 1300° C., weld specimens of 19/9/1 Nb and 18/13/1 Nb alloys were heat-treated at 1100–1400° C., and quenched. The essential microstructural changes in 19/9/1 weld are shown in Fig. 7. At 1100° C., carbides are present in the ferrite islands and also in areas where ferrite existed before heat-treatment (Fig. 7*a*). Figure 7*b* shows slightly more ferrite at 1300° C. compared with that at 1100° C., and the carbides have largely dissolved. At 1400° C. the ferrite has increased greatly to become the matrix with islands of austenite (Fig. 7*c*). The grain size has increased appreciably, and considerable homogenization has taken place.

It may be inferred that 19/9/1 Nb welds solidify with primary dendrites of ferrite and the alloy-enriched liquid forms a little austenite in inter-dendritic areas. From 1400° to 1350° C. austenite increases in volume by absorbing the ferrite and thus forms new boundaries in the primary dendrites, *i.e.*, the austenite boundaries no longer coincide with low-melting-point segregation.

18/13/1 *Weld*—The weld treated at 1100° C. shows austenitic matrix with a concentration of niobium carbides in the grain boundaries (Fig. 8*a*). At lower magnification persistent coring was evident at all temperatures. The specimen heated at 1300° C. has a similar structure (Fig. 8*b*), whilst after heat-treatment at 1400° C. a eutectic-like constituent appears in the boundaries (Fig. 8*c*). An X-ray photograph of the residue from this sample indicates more lines than are given by NbC. It may be inferred that the duplex constituent is some compound of niobium. An 18/13 weld without niobium, heat-treated at 1400° C., does not contain this eutectic-like phase (Fig. 9) although the alloy still cracks.

19/9/3 *Mo Weld*—Figure 10 shows an increase in ferrite from 1100° to 1400° C. In contrast to the 19/9/1 Nb weld (Fig. 7*a*), no carbides are present at 1100° C.

DISCUSSION

The results obtained indicate that micro-cracking in the austenitic weld metal occurs in an intercrystalline manner above 1290° C.; this eliminates the possible effect of the sigma-phase. No definite intercrystalline constituent has been identified as being responsible for the phenomenon. Although a eutectic-like phase is present in alloys containing niobium, it is absent in the plain 18/13 alloy, which also cracks. Thus, this eutectic-like phase does not appear to be essential and, in the absence of further evidence, it may be inferred that the weakness of the grain boundaries does not result from precipitation, but is caused by the concentration of some element at the grain boundary, while still remaining in solution. For temper-brittle steels McLean[5] and McLean and Northcott[6] have shown that in a solid solution the composition of the crystal may be different from that of the grain boundaries. In a weld this difference in composition is intensified by coring.

The grain boundaries can be considered as a transition lattice in which some iron atoms will occupy larger and some smaller volumes than in a perfect lattice. The resulting local elastic stresses represent a high energy and therefore instability in the structure. This energy may be reduced by placing atoms with large atomic radii in the spaces between the atoms occupying large volumes, *i.e.*, to prevent 'rattling of atoms.' In a similar way very small atoms may be put into the small spaces. Consequently, the energy of the whole mass will be reduced if elements having an unfavourable size factor relative to the solvent, according to the Hume Rothery Criterion, move from the lattice in the crystal to more suitably matched spaces in the boundary region.

The relative sizes of relevant alloy elements are given in Table III, from which it will be seen that Ni and Cr are likely to be fairly stable in the lattice. On the other hand Si, Nb, and C, because of their size, are likely to diffuse to the grain boundary. The combination of small Si and C atoms and large Nb atoms produces in the transition zone of the boundary a stability associated with an increase of strength at the elevated temperature. To become really effective certain ratios of Nb and Si may be necessary.

The melting points of Nb and C are high and this might be expected to increase the strength of the boundary. The melting point of Si, however, is lower than iron, and in the absence of Nb may tend to form incipient $FeSi_2$ or FeSi with melting points about 1210° C. The results already obtained indicate that Si is an important factor in promoting cracking of austenitic alloys, and is likely to have a major influence on crack formation in the plain 18/13 alloy. The niobium in the 18/13/1 alloy will tend to counterbalance the effect of silicon and reduce cracking, which agrees with results obtained. The addition of more than 0·09% of C forms a 'padding' in the vicinity of the Si atom and reduces cracking.

Table III

RELATIVE SIZES OF ALLOYING ELEMENTS

	Fe	Ni	Cr	Si	Nb	C
Atomic dia. (closest approach)	2·48	2·48	2·50	2·34	2·85	1·42
Melting point, ° C.	1539	1455	1890	1430	2415	3700
Structure at 1300° C.	f.c.c.	f.c.c.	b.c.c.	diamond	b.c.c.	cubic

Even with an optimum composition, however, fully austenitic multi-run welds micro-crack under certain stress conditions, and the only known crack-resisting alloy is the duplex one.

The crack-free property of the duplex alloy may be attributed to three contributory factors. The silicon may fit better in the ferrite lattice with less tendency to take boundary sites. Secondly, the extent of boundary area is increased and any intercrystalline concentration of precipitate is thereby diluted and rendered less dangerous. The third results from the fact that the austenite grain boundaries do not coincide with the primary segregation existing at the solidus.

The alloy also appears more homogeneous than is the case of the plain austenitic alloy, which exhibits persistent coring. The beneficial effect of a homogeneous structure has been demonstrated by the interpass heat-treatment at 1100° C. This smaller segregation may be attributed to a shorter solidification range compared with that of an austenitic alloy.

CONCLUSIONS

(1) Micro-cracks in the austenitic alloys are intercrystalline and occur mainly in beads of weld metal reheated above 1250° C.

(2) Internal stresses and heterogeneity in the structure are contributory factors.

(3) Although sulphur reduces resistance to hot-cracking it does not appear to be a major factor in causing micro-cracks. Other non-metallic inclusions have little effect.

(4) Silicon appears to be a major contributory factor on boundary cohesion, although its influence is reduced if sufficient is present to form ferrite.

(5) The addition of 1–1½% of niobium, and of carbon in excess of 0·09%, has a beneficial effect.

(6) The presence of a minimum of about 5% of ferrite obviates micro-cracking, although long-duration treatment at 650–950° C. embrittles the alloy by forming the sigma-phase. Small amounts of sigma can be tolerated (*e.g.*, 7%).

This improvement is ascribed to the accommodation of silicon in the ferrite lattice, greater boundary area, and a lack of coincidence of final boundaries and primary coring.

Acknowledgments

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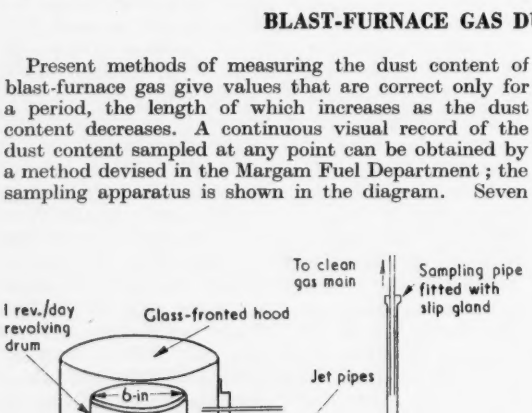
Letter to the Editor

BLAST-FURNACE GAS DUST-CONTENT INDICATION

Present methods of measuring the dust content of blast-furnace gas give values that are correct only for a period, the length of which increases as the dust content decreases. A continuous visual record of the dust content sampled at any point can be obtained by a method devised in the Margam Fuel Department; the sampling apparatus is shown in the diagram. Seven evenly spaced records of a 24-hr. period are made on each 'chart' of white lint.



Saturated blast-furnace gas was tested after passing through a single-stage wet Lodge Cottrell gas cleaning plant; the gas was usually cleaned to an average dust content of approx. 0·003 grains/cu. ft. A ¼-in. gas pipe from the clean gas main was taken vertically to approx. 1 ft. from the cleanliness recorder where a sample pipe was taken at right angles to the vertical gas pipe allowing a substantial vertical drain leg after the sampling point. The lint-covered drum was protected from possible atmospheric interference by a glass-fronted hood to which were fitted seven ⅛-in. I.D. copper jet pipes set horizontally, approx. 1 in. apart, and one above the other. The sample pipe was connected by rubber tubing to each of the jet pipes so that the top jet could be used on the first day and so on on each successive day. Thus one lint chart sufficed for one week and a comparative record of gas cleanliness could be obtained for that period.

Although the apparatus has limitations it shows clearly and immediately any changes in the degree of cleanliness and the exact time of their occurrence.

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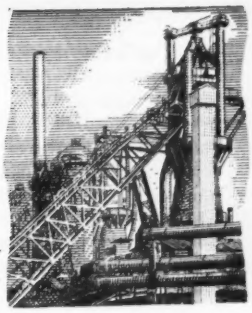
BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Desulphurization of Pig Iron by Solid Lime

By V. Giedroyc, Ph.D., D.I.C., and T. E. Dancy, Ph.D., D.I.C., A.R.C.S.

SYNOPSIS

The possibility of using solid lime for the desulphurization of pig iron has been examined, and the necessary data to assess the practicability of this process have been obtained. These include measurements of the rate of reaction and the influence of sulphur concentration and temperature on the process. An estimate has been made of the surface area of lime required to obtain a given degree of desulphurization.

Introduction

THE problem of the removal of sulphur from pig iron is becoming more acute, since the sulphur content of the raw materials for ironmaking is likely to increase in the future. Although low-sulphur pig iron can be obtained by the appropriate burdening of the blast-furnace, it might be more economic, particularly when processing home ores, to accomplish the desulphurization outside the furnace. Therefore, the development of a rapid and effective method is of particular importance.

Oelsen and Maetz[1] give experimental evidence of the predominant importance of area of contact in desulphurizing reactions in a blast-furnace. They considered that reactions between solids might proceed more rapidly than reactions between liquid pig iron and liquid slag, provided that a larger area of contact between the reactants could be established. Because the desulphurizing power of a slag is related to its basicity, lime or calcium carbide have often been used as desulphurizing agents; Baumer and Hulme[2] have successfully desulphurized iron by calcium carbide on both a laboratory and a pilot-plant scale. Burnt lime, which is cheaper, has been used with fluxing agents to obtain liquid slag,[3–5] although attempts to desulphurize with lime alone have also been made.[6–8]

While the experimental work described in this paper was in progress, Kalling[9] and Fornander[10] reported the desulphurization of pig iron by powdered lime on both a pilot-plant and an industrial scale. The method of desulphurization consisted of the treatment of molten pig iron with 2% powdered lime and 0·5% coke breeze in a rotary furnace (34 r.p.m.) for 30 min. Information on the necessary amount of lime and rates of reaction was also given. Although these authors covered some of the kinetics of the desulphurization process, their approach was practical rather than fundamental.

Since the desulphurization of pig iron by solid lime is mainly a surface reaction, in the work described in this paper an attempt has been made to determine the relationship between the extent and velocity of sulphur removal and the reacting lime surface.

MATERIALS

Certain facts are known concerning the influence of manganese and silicon upon the desulphurization of pig iron.

Chipman and Ta Li[11] concluded that manganese aids desulphurization according to the reaction : (FeS) + (MnO) = (FeO) + (MnS). Kohler[12] considered that a decrease of manganese below the usual content has no effect on desulphurization, but that a high manganese content accelerates desulphurization, owing to its indirect effect on the deoxidation of the slag and metal bath (not because of the direct action of manganese). Scott and Joseph[13] showed that the presence of manganese in the metal increases the desulphurizing power of calcium silicate slags. Kootz and Oelsen[14] and Fetters and Chipman[15] concluded that, when slag basicity and sulphur distribution are considered, the equivalent of MnO in the slag should be added to that of CaO to obtain a measure of slag basicity. Silicon is shown to play the

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rôle of a reducing agent according to the reaction : $(2CaO) + [2FeS] + [Si] = (SiO_2) + (2CaS) + [2Fe]$.

Both manganese and silicon, either directly or indirectly, have a beneficial influence on the desulphurization process. However, in the case of desulphurization with solid lime, silica formed by oxidation of silicon during the process $2[FeS] + 2(CaO) + [Si] \rightarrow 2[Fe] + 2(CaS) + (SiO_2)$ will react with lime, binding some of the lime particles together and adhering to unused lime surface, thus diminishing the available reacting area.

To simplify the interpretation of results, in all the present experiments Armco (*ADX*) iron was used, to which carbon and ferrous sulphide were added in amounts sufficient to saturate the iron with carbon and bring the sulphur content to the required amount. The analysis of the Armco iron is as follows :

Element	%	Element	%
C	0·026	Al	<0·005
Si	<0·02	Cu	<0·05
Mn	<0·05	W, Ti, Co, Sn, Pb	<0·02
S	0·035		
P	<0·008	Cr, Mo, V	<0·01
Ni	0·038		

The desulphurizing agent was prepared from pure calcium oxide, which was slaked and mixed to a stiff paste with water and then rolled by hand into balls of the required size. After air-drying for 24 hr., the balls were slowly ignited to 1000° C. and finally, for about 5 min., to 1400° C. When lime is maintained at 1400° C. crystal growth occurs,[16] diminishing its surface area and thus considerably lowering its reactivity. Therefore, in addition to the lime balls that had been finally fired at 1400° C., some samples were prepared with a final firing temperature of only 1200° C. Preparation of the lime balls was carried out very carefully, since the process being studied was a surface reaction and variations in surface would have a great influence upon desulphurization.

PRELIMINARY EXPERIMENT

An introductory experiment was made to ascertain whether significant desulphurization occurred when iron was allowed to pass over solid lime. A sample of iron containing 0·9% of sulphur was run through a column of 0·5-cm. dia. lime balls contained in a carbon tube of 2·5 cm. internal diameter, which was then heated to 1400° C. in a molybdenum furnace. To assess the degree of desulphurization the iron was analysed for sulphur before and after passing through the column. After the first passage down the column the sulphur content of the iron had diminished by about 10%; after the fifth passage the sulphur content in the same sample had decreased to 0·45%. Only about 1 cm. at the top of the column had been affected, indicating that the stirring action of the falling iron meeting the top of the lime column assisted desulphurization, whilst the rivulets of iron flowing through the lower part of the column were not subjected to such violent agitation. The time taken for a given particle of iron to pass through the column was estimated to be not more than 1 sec.

To determine the influence of sulphur concentration, the experiments were repeated in the same apparatus. The percentages of sulphur in the iron, after each passage, are plotted in Fig. 1. In Fig. 1*b* the number of passes through the column (approximately equivalent to time of contact, in seconds) are plotted against the sulphur concentration in the iron on a logarithmic scale. The straight line obtained shows that the desulphurization process behaves as a first order reaction, indicating that the main controlling factor under the conditions of these experiments, where there was always adequate lime surface available, was the concentration of sulphur in the iron.

IMMERSION EXPERIMENTS

To obtain a more precise idea of the surface area of lime necessary to desulphurize a given quantity of pig iron, experiments were designed using larger lime balls, the surface areas of which could be measured more accurately. These were made in the same manner as the smaller balls, and were fired in the same way.

The average temperature at which iron from a blast-furnace can be processed is 1400° C., and this temperature was accordingly used for most of the experiments. The investigation was divided into the following groups :

(i) The influence of time on desulphurization
(ii) The relation between surface area of lime and the amount of desulphurization, for reaction times of 1 sec. and 1 min.

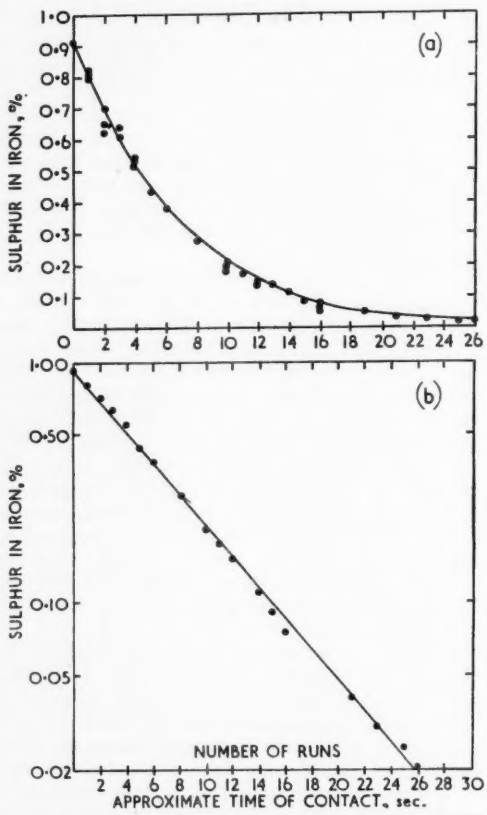

Fig. 1—Results of preliminary experiment to show the influence of sulphur concentration : (*a*) Plotted directly ; (*b*) plotted on a logarithmic scale

(iii) The effect of sulphur concentration in the iron on desulphurization
(iv) The influence of iron temperature on desulphurization.

Apparatus

The apparatus used for these immersion experiments is shown diagrammatically in Fig. 2. The crucible containing the iron was made of 'Link *EY* 2' carbon rod ; it had an internal diameter of 4 cm. and was 8 cm. deep, and rested on an alumina ring. This ring acted as a thermal insulator between the crucible and the carbon support, through which passed a closed-end ΔH thermocouple sheath terminating in a recess in the base of the crucible. By this means the temperature of the iron could be measured fairly accurately with a Pt/Pt–Rh thermocouple. The assembly was supported in a molybdenum wound-resistance furnace by a sillimanite tube, which enabled the crucible to be raised or lowered while hot. To allow the maximum amount of surface of the ball to come into contact with the iron when immersed, the lime ball was held in a carbon cage between three carbon points and a carbon knife-edge. The carbon points were held in tight contact with the ball by a closed-end ΔH thermocouple sheath, which was pressed into a recess in the top of the carbon cylinder in which the points were mounted. This sheath passed down the centre of a silica tube from which the cage was suspended. The whole assembly could be clamped in any position above the surface of the iron so that the ball could attain a predetermined temperature before immersion. The cage was lowered or raised by hand, the time of immersion being measured by a stopwatch.

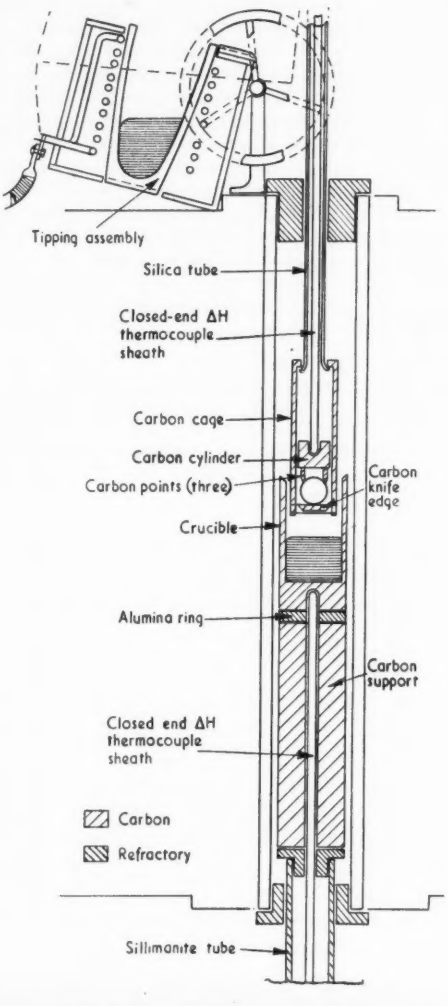

Fig. 2—Diagram of apparatus

Experimental Procedure

The empty crucible on its supports was mounted in the furnace and was heated to 1400° C. At the same time, the iron sample containing the required quantity of carbon and sulphur was melted in a fireclay pot by an induction coil fixed in a tipping assembly on top of the molybdenum furnace. When the molten iron had reached 1400° C. a sample was taken, the carbon crucible was raised, and a measured quantity of iron was poured into it. The crucible was lowered immediately, and the iron temperature was therefore stabilized very quickly. A lime ball in the cage was then fixed in position above the iron and allowed to reach the temperature required, which was measured by the top thermocouple ; the iron temperature was measured by the thermocouple in the base of the crucible. These temperatures were indicated on a direct reading galvanometer, and may be considered correct to $\pm 5°$ C.

After both temperatures were stabilized, the ball was lowered into the iron for the prescribed time. Then the whole assembly was transferred from the furnace into a closed-end carbon tube cooled externally with water. Meanwhile, a further ball in another assembly was placed in position in the furnace, and the procedure was repeated. After a series of experiments the crucible was raised to the top of the furnace and the iron poured out. A fresh sample of molten iron was then introduced from the induction heated pot and the process was repeated as before.

Velocity of Reaction

To determine the relationship between reaction time and the amount of sulphur removed, lime balls of approximately equal apparent surface, and iron containing 0·15% of sulphur were used. The apparent surface may be defined as the surface area of the ball determined from its mean diameter. Since the surface of the ball was not smooth, the 'apparent' surface was always much smaller than the real surface.

The lime balls were immersed for periods of 1, 2, 10, 20, and 30 sec. and 1, 2, and 5 min. In Fig. 3 the weight of sulphur removed per sq. cm. of apparent ball surface is plotted against immersion time, and the resulting curve suggests that three stages in the reaction can be considered :

(1) The purely surface reaction is very fast, as is shown by the steep rise of the initial part of the

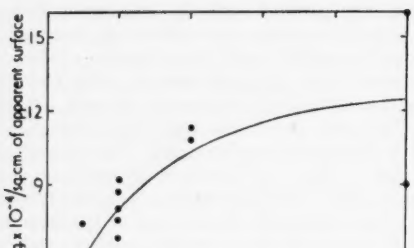

Fig. 3—Velocity of reaction

curve (immersion time = 1 sec.). During this period, ferrous sulphide from the layer of iron in immediate contact with the surface of the ball is reacting.

(2) In the second stage (from 2 sec. to about 2 min.) the surface reaction probably continues but is slowed down by the layer of desulphurized iron, in immediate contact with the surface, through which sulphur must diffuse before the reaction can continue. Violent agitation would probably decrease the effect of this desulphurized iron layer and improve the rate of desulphurization.

(3) The third stage is reached when the surface of the lime has completely reacted, and thus the rate of diffusion of sulphur through the solid is probably the governing factor. This slow stage of the reaction is not of great interest where application to large-scale industrial processes is considered, and effort should be directed towards increasing the scope and effect of the faster reactions and hence the rate of desulphurization.

The arbitrary division of the reaction into three stages was attempted so as to obtain a clearer picture of the probable mechanism of the reaction ; it also indicates the limit of the useful time of contact between the pig iron and the desulphurizing medium.

Experiments were also made in which lime balls were immersed in iron for various times and then examined microscopically. The reacted balls were embedded in Diakon, cut in half, the exposed surface ground flat, and a cover slip attached with Canada balsam. There was a coloration of the lime by ferrous oxide, and the thickness of the reacting layer could therefore be observed. The results of these observations are as follows :

S in Iron, %	Reaction Time	Average thickness of Reacted Layer, mm.
0·11	1 sec.	0·10
0·11	2 sec.	0·11
0·11	30 sec.	0·25
0·11	1 min.	0·25
0·11	10 min.	0·30
0·77	1 sec.	0·30
0·77	5 sec.	0·20
0·77	1 min.	0·35
0·77	5 min.	0·30

Even after 10 min., the average depth of penetration was only 0·3 mm. Since only a small portion of the lime participated in the reaction, excessive use of lime could be avoided either by using smaller particles or by coating coke, crushed slag, or other inert material.

The chemical composition of the surface layer of a lime ball after reaction was studied by X-ray diffraction, and the only clear lines observed were those of CaO and CaS. Since no iron or iron oxide lines were detected, it must be assumed that there was less than 5% of both of these in the surface layer, and therefore loss of iron in the spent lime was negligible.

Influence of Surface Area of Lime

Since differences in the diameters of the lime balls were of the order of 3 mm., it was convenient to express the amount of sulphur removed in g./sq. cm. of apparent surface of lime. To justify this method of expression, a series of experiments was made in which the sulphur concentration, temperature of the iron, and the time of reaction were kept constant, and only the size of the lime balls was varied. Velocity of reaction experiments indicated that only the first stages of the desulphurization process (*see* p. 355) were likely to be of interest in any industrial application. Therefore, two independent series of experiments for immersion times of 1 sec. and 1 min. were carried out.

The results of these experiments are plotted in Fig. 4. Although the scatter of points was considerable, the assumption that there was a direct proportion relationship between apparent lime surface and sulphur removed from the iron seemed justified, owing to the narrow limits of variation of ball sizes used in all other experiments.

Effect of Sulphur Concentration

The preliminary experiment showed that sulphur concentration in the iron has a profound influence on

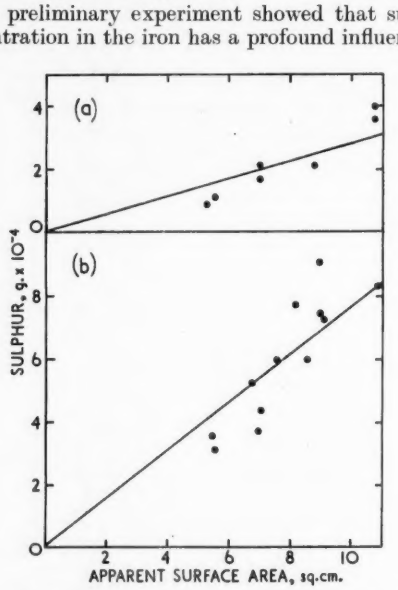

Fig. 4.—Influence of surface area of lime, for iron containing 0·15% of sulphur : (*a*) Reaction time = 1 sec.; (*b*) reaction time = 1 min.

the amount of desulphurization obtainable under the conditions of test. To obtain the information necessary for the calculation of the surface area of lime needed to obtain a given degree of desulphurization, a large number of experiments were carried out in which only the sulphur concentration was varied. The iron temperature for all these experiments was 1400° C., and the amount of desulphurization was measured after both 1 sec. and 1 min. Experiments were performed using balls that had been fired (i) to 1200° C. and (ii) to 1400° C. The temperatures of balls of type (i) were not allowed to rise above 1200° C. while suspended above the iron surface before immersion.

Although the scatter of points in Fig. 5 is considerable, owing to the unavoidable variations in the quality of the balls, the results show very conclusively the much greater desulphurizing power of the balls fired to the lower temperature. The influence of sulphur concentration in the iron on the amount of desulphurization is considerable for both reaction times. The curves show that to lower the sulphur concentration from 0·3% to 0·05% in 1 min., 50% more lime surface would be required than to diminish it to 0·1% in the same time.

Since the surface of the lime was saturated in a few minutes, the data obtained for a reaction time of 1 min. can be used to calculate the surface of lime necessary to desulphurize a given quantity of iron. The upper limit of sulphur concentration was taken as 0·3% ; a much higher value is not likely to be met in practice, even with acid burdening. The lower limit was considered to be 0·05%, which represents an average value obtained in British blast-furnace practice.

Taking the log mean of 0·3 and 0·05% sulphur, *i.e.*, 0·14%, the sulphur removed (Fig. 5*b*) is 7×10^{-4} g./sq. cm. of apparent lime surface. Therefore, 1 sq. m. of lime surface will remove 7×10^{-3} kg. of sulphur in 1 min. If the lime is used in the form of 0·5-cm. dia. spheres, 630 sq. m. of lime surface will be available in a volume of 1 cu. m., if the lime spheres are arranged in cubic close packing. Thus, 1 cu. m. of 0·5-cm. dia. spheres will remove 4·4 kg. of sulphur, so that, to decrease the sulphur in 1 ton of pig iron from 0·3% to 0·05% in 1 min., the necessary lime surface in the above form and packing will require a volume of 0·57 cu. m. (approx. 20 cu. ft.).

Influence of Iron Temperature

Duplicate experiments were made, using iron with a sulphur content of 0·15%, for 1 sec. and 1 min. immersion times over a temperature range from 1300° to 1550° C. The temperature of the balls before immersion was held at 1200° C. since at higher temperatures the effect of the recrystallization of the calcium oxide would have completely subordinated the effect of temperature variations. The results are plotted in Fig. 6, in which the sulphur removed is calculated on the original surface of the ball and not on that after immersion.

Sulphur removal during the first second is not significantly influenced by temperature, doubtless because the reaction is almost entirely on the immediate surface. During 1 minute, the diffusion of sulphur through the surface layer of iron is the controlling factor, and this is seen to have a considerable temperature coefficient. The rate of improvement of desulphurization seems to decrease above 1500° C., but this may be brought about by the alteration of lime surface after immersion, due to the crystallization of calcium oxide.

CRUCIBLE EXPERIMENTS

Determination of Saturation

After estimating the desulphurization possible with a given surface area of lime, experiments were performed to determine the quantity of sulphur necessary for its saturation.

A fireclay crucible with a fitting lid was completely filled with lime balls (mean diameter 0·4 cm.) and was pre-heated to 1000° C. The total surface area of the lime was 187 sq. cm. An amount of 200 g. of pig iron was melted by induction, heated to 1400° C., and then transferred to an induction coil so that the iron

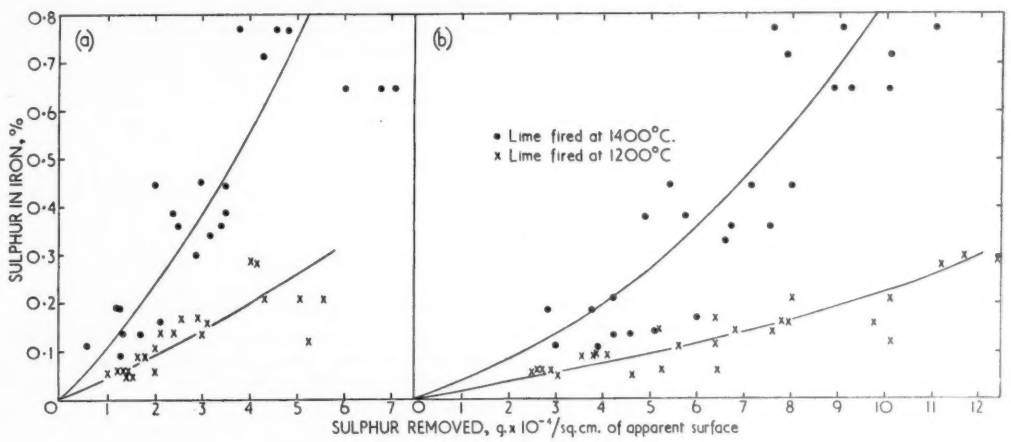

Fig. 5—Effect of sulphur concentration on desulphurization, for lime balls fired at 1200° and 1400° C. : (*a*) Reaction time = 1 sec. ; (*b*) reaction time = 1 min.

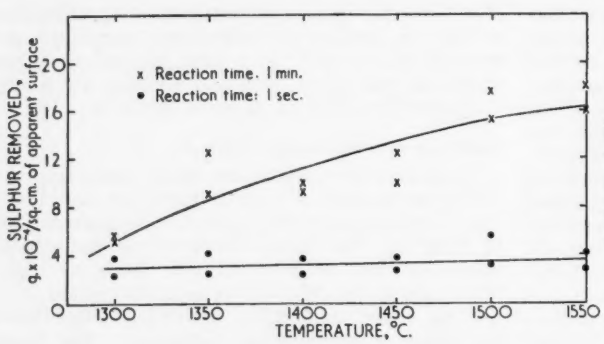

Fig. 6.—Influence of iron temperature on desulphurization, for iron containing 0·15% of sulphur

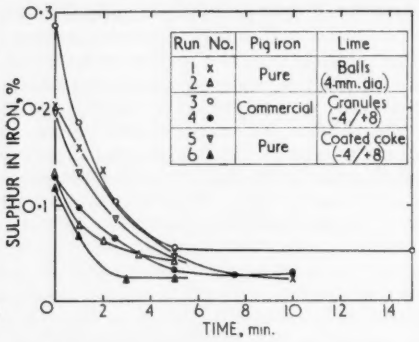

Fig. 7—Rate of desulphurization using pure lime and lime-coated coke

temperature could be maintained during the reaction. The iron sample was sufficient to fill the voids between the balls, and the crucible lid prevented the lime from floating, so that nearly all the lime surface was in contact with the iron. Small samples of iron were withdrawn at intervals and analysed for sulphur. When there was no further decrease in sulphur content the lime surface was considered saturated. Results are given in Table I.

In the first two experiments the iron was left in contact with the lime until no further desulphurization occurred. In the third experiment two successive samples were poured in turn into the same lime, to confirm that the lime, which appeared to be saturated after 12 min., was not capable of extracting sulphur from a new sample in spite of the agitation provided by the change of iron. In the last experiment, a very high sulphur concentration was maintained by replacing the original iron by a second sample before the sulphur concentration in the iron had dropped very far. After 5 min. the second sample was replaced by a third, but no further desulphurization occurred.

These experiments gave an indication of the amount of sulphur capable of being extracted from pig iron by a particular area of lime surface; the saturation value for the surface is greater when the initial sulphur concentration in the iron is high.

The saturation value of the lime surface as determined by these experiments must be low, for the following reasons:

(1) When the balls were examined after the experiments, there was always some lime surface which did not appear to have been in contact with iron.

(2) The quantities of iron used were so small that even slight oxidation was likely to have a significant influence on the desulphurization process.

(3) Some slagging of the lime in immediate contact with the crucible was observed, especially when the reaction time was greater than 5 min.

Table I

RESULTS OF SATURATION EXPERIMENTS

Experiment	Sulphur in Iron, %		Time of Reaction, min.	Saturation Value × 10^{-3}, g./sq. cm.	
	Initial	After Reaction			
1	0·287	0·059	15	2·44	No further decrease after 15 min.
2	0·287	0·061	15	2·42	
3*a*	0·259	0·079	12		Same lime used in *a* and *b*
b	0·106	0·106	10	2·2	
4*a*	0·626	0·353	5		Same lime used in *a*, *b*, and *c*, successively
b	0·560	0·467	5		
c	0·417	0·417	5	3·9	

Desulphurization With Pure Lime

Further experiments were carried out to determine the rate and extent of desulphurization when hot iron was poured into a crucible filled with lime balls (3–4 mm. dia.) or crushed lime (− 4/+ 8 mesh). The weight of lime used in these experiments was of the order of 20–25% of the weight of iron. The experimental procedure was the same as that used for the saturation experiments (*see* p. 357), and the results are given in Fig. 7. The initial rate of desulphurization was not as great as was expected, owing to cooling of the iron, and it was only after some minutes that the temperature could be restored to 1400° C. In these experiments, agitation between the iron and lime occurred only when the iron was first poured into the lime and when the crucible was tipped during the withdrawal of samples. Two pure and two commercial pig irons were desulphurized (runs 1–4, respectively, Fig. 7); the presence of silicon and manganese in runs 3 and 4 only slightly improved the process.

Desulphurization With Lime-Coated Coke

In a large-scale process it would obviously be prohibitive to use as much as 25% by weight of lime; however, by coating coke (− 8/+ 10 mesh) with lime, approximately the same surface can be provided using only about 5% by weight of lime. The coated coke used in the experiments contained 25% lime and 75% coke by weight. After use the coke could be washed and recoated with lime. A satisfactorily

covered coke was made by immersing it in a lime slurry and then drying, screening, and igniting to 1000° C. The lime became firmly attached to the coke, with very little powdering.

Runs 5 and 6 (Fig. 7) were made using coated coke as the desulphurizing agent. Desulphurization from either 0·2 or 0·1% of sulphur is more rapid than with pure lime, probably because of the reducing conditions brought about by the presence of the coke.[17] In these experiments there was no slagging; the coated granules did not adhere and were quite separate after use.

CONCLUSIONS

The following main conclusions may be drawn from this work :

(1) Extensive desulphurization of iron using solid lime is possible in a comparatively short time.

(2) Quantitative experiments showed that the desulphurization process could be arbitrarily divided into three stages : a very fast surface reaction, a slightly slower reaction probably controlled by diffusion of sulphur through a layer of desulphurized iron, and a much slower solid diffusion stage. Only the first two stages are likely to be of interest in a simple large-scale desulphurizing process, and great improvement can be obtained by violent agitation. Microscopic examination of sectioned lime balls showed that, even after 5 min. contact with iron containing 0·2% of sulphur, the reaction had not penetrated more than 0·3 mm. For this reason, a coating of lime on some inert material would be as useful a desulphurizing medium as would lumps of pure lime.

(3) The concentration of sulphur in the iron is an important factor in the desulphurization process. In practice, larger surfaces and longer times of contact could be obtained, so that exhaustive desulphurization should be possible.

(4) The desulphurizing ability of lime fired to 1200° C. is much greater than that fired to 1400° C. ; the lime reactivity, therefore, would be considerably reduced after contact with hot iron for a long period. The beneficial influence of increased temperature, although significant, would be offset in practice by the simultaneous crystallization of lime. Operation at temperatures much below 1400° C. is unlikely to be possible, because of the low fluidity of the iron.

(5) From the results of the experiments (Fig. 5) it was calculated (p. 357) that the volume of plant necessary to desulphurize 1 ton of iron (from 0·3% to 0·05% S) would be about 20 cu. ft. However if the time of contact could be increased to allow the saturation value (Table I) to be attained, the required volume would be reduced to approximately 7 cu. ft./ton.

(6) The desulphurization of a commercial pig iron by granulated lime is very little better than that of an artifically prepared pure pig iron.

(7) When lime-coated coke is used for desulphurization, the reaction proceeds more quickly than with pure lime. The use of this material has the advantages that (*a*) it enables a granular material to be used without an excessive consumption of lime : the amount employed is comparable with that used in the Kalling process, and the spent material can be washed and recoated with lime, or used directly in a sinter mix ; (*b*) reducing conditions are maintained in the reaction zone without special precautions for the exclusion of air ; and (*c*) the adhesion of particles due to slagging is minimized.

Although the practicability of the use of powdered lime has been demonstrated by the Kalling process, the present work has shown that adequate lime surface for desulphurization can be provided by a reasonable volume of granular material, and this would allow the use of simpler plant suitable for handling much larger quantities of pig iron. Coated coke is definitely superior to granulated lime, but whether it is best used in a batch, semi-continuous, or continuous desulphurizing process, can only be determined by pilot-plant experiments.

Acknowledgments

The work described was carried out at the Imperial College of Science and Technology, South Kensington, and the authors wish to express their sincere thanks to Dr. H. L. Saunders, Head of the Iron Making Division of the British Iron and Steel Research Association, for supervision and helpful advice in the course of the investigation, and for permission to publish this paper.

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Studies on Anti-Fouling Compositions

FOREWORD

This paper forms part of a series of studies on anti-fouling compositions. The first three papers were published in the December, 1947, issue of the *Journal*. Part I was a general introduction to the whole series. Part II described the probable reactions occurring between the components during preparation of varnish and Part III gave details of a study of the rate of loss of materials from a series of varnish media immersed in the sea over two consecutive 40-day periods. Part IV, published in the June, 1948, issue of the *Journal*, determined critical leaching rates for a number of common fouling organisms and compared copper loss under service and raft exposure conditions. Part V, published in October, 1948, gave consideration to the behaviour of mercuric oxide in some anti-fouling compositions, paying particular attention to the leaching-rate test. Part VI, published in the June, 1949, issue of the *Journal* considered the leaching rate during early stages, and its relation to surface conditions in cuprous oxide compositions. The present paper, Part VII, considers the leaching rate during the middle and late stages.

Part VII—The Leaching Rate During the Middle and Late Stages of Compositions Based on Cuprous Oxide as the Toxic Component

By H. Barnes, B.A., B.Sc., Ph.D., F.R.I.C.

SYNOPSIS

The various factors affecting the leaching rate of compositions containing cuprous oxide, during the middle and late stages of immersion, are considered.

The results are based on leaching-rate studies made on a wide variety of compositions formulated to elucidate these factors. Of major importance are the cuprous oxide content and the matrix formulation. The latter, with a given cuprous oxide content, determines the leaching rate.

With many of the compositions investigated the leaching rates dropped below their 'steady' value in the very late stages of soaking. This appears to be caused largely by the building up of a skeletal matrix residue. Methods are suggested whereby formulation can be adjusted to avoid this disadvantage.

Introduction

THE general theory on which the behaviour of anti-fouling action of paints is explained in this series of papers has already been briefly summarized, and a more detailed account of some aspects of the problem has been given, together with an account of the relevant experimental work.[1–9] The leaching rate of compositions in the early stages of soaking has been dealt with in some detail, and, although in some circumstances this initial behaviour has been shown to be of considerable practical importance, the behaviour in the later stages, *i.e.*, when the surface copper, or varnish, has been removed, is more important in assessing the overall efficiency of a composition. The effect of a number of factors on the middle and later stages of the leaching process in cuprous oxide compositions is considered in this paper.

In a simple model of the leaching-rate process the intrinsic rate of solution of both cuprous oxide and the matrix resins in sea water is dependent upon a number of factors, for example, temperature, salinity, and *p*H. Under normal working conditions the intrinsic rate of solution of the former is about 250 μg./sq. cm./day and of the latter 100 μg./sq. cm./day (or less) but these rates may change during immersion.[1, 5] Since the matrix dissolves at a slower rate than the cuprous oxide, it would be expected that the former would be the controlling factor in determining the observed leaching rate. For a steady leaching state,

$$L_1/L_2 = W_1/W_2 \text{ or } L_1 = L_2W_1/W_2 \quad \ldots\ldots\ldots(1)$$

where L_1 and L_2 are the rate of loss of cuprous oxide and matrix, and W_1 and W_2 their weight fractions in the composition. For a simple system of two components, toxic and matrix, it follows from (1) that the leaching rate of the toxic is,[10]

$$L_1 = W_1RV_2/W_2 \quad \ldots\ldots\ldots(2)$$

where R is the intrinsic rate of solution of the matrix and V_2 is its volume fraction in the composition.

EFFECT OF THE MATRIX COMPONENTS

The matrix in a simple system consists of a soluble material (an acidic resin, usually rosin), a binder, and a plasticizer, although some materials may function

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Dr. Barnes, formerly with the British Iron and Steel Research Association, is now on the staff of the Scottish Marine Biological Association.

Table 1
LEACHING RATE AND MATRIX COMPOSITION

Rosin in Matrix, %	87·5		83·3		75·0		71·4		66·6		60·0		50·0	
Soaking Time, days	29–71	185	29–71	185	29–71	185	29–71	185	29–71	185	29–71	185	29–71	185
Bedesol	30·3	12·6	29·6	12·7	14·3	13·1	5·4	11·9	4·5	11·3	2·9	13·1	3·3	15·1
Ester Gum	26·0	12·9	16·2	9·2	6·6	7·4	3·5	8·9	3·3	8·8	3·2	7·1	...	8·6
Hydrogum	28·4	14·9	23·1	11·0	20·1	8·8	16·2	7·7	14·8	7·1	16·1	8·8	14·5	6·4
Beck (1)	34·9	22·3	30·7	20·3	29·5	19·4	22·8	19·1	...	19·6	...	16·5	2·9	7·2
Beck (2)	16·9	9·9	4·0	6·8	...	4·3	3·0	6·2	...	4·6	...	2·2	3·4	1·6

as both binder and plasticizer. If the added binder and plasticizer do not affect the rate of solution of the rosin and come away as the latter is dissolved, then the rate of loss of the matrix, *i.e.*, L_2 in equation (1), remains constant. However, the binder materials often affect the rate of solution of the rosin (*see* p. 363). The mean leaching rates after 29–71 days of a series of compositions prepared with five different binders, namely, Bedesol/stand-oil, ester gum, hydrogum, and two Beck resins, each with a small amount of methyl abietate as plasticizer are given in Table I. In these compositions both the cuprous oxide content and the total matrix content were maintained constant, but the proportion of rosin to binder in the matrix was varied. The leaching rate is shown to be a function not only of the rosin/binder ratio, but also of the specific character of the binder itself. In all the compositions, however, there is a reduction in the steady leaching rate as the proportion of binder in the matrix is increased until, with the exception of the hydrogum compositions, the leaching rate is negligible at a 1/1 rosin/binder ratio.

This effect of the rosin/binder ratio on the leaching rate is similar to its effect on the rate of loss of material from unpigmented varnishes, showing that the rate of solution of the matrix controls the copper-leaching rate. The smaller effect with the hydrogum compositions, is, however, not in agreement with the results obtained on the rate of loss of varnishes ; the reason for this discrepancy is not clear. In Fig. 1 the steady copper-leaching rates for a number of compositions with several intermediate rosin/binder ratios, with both ester gum and Bedesol as binders, are plotted against the observed rate of loss of material from the equivalent varnishes. The steady leaching rate is only approximately proportional to the rate of loss of matrix given by equation (1), which suggests that the simple system for which equation (1) holds does not exist in practice. The rates of solution of the matrix, as determined from the varnish exposures, may be affected by the presence of both inert pigments and cuprous oxide in the formulated paint. The effect may vary according to the nature of the binder because of physical factors, such as the hardness of the resin and the effect on this of the dispersed pigment particles in the matrix, or of chemical factors, such as interaction of the matrix with the cuprous oxide. Interaction of the cuprous oxide and matrix has already been stressed[1] and it has been shown that, during milling, interaction of the cuprous oxide and the acidic rosin (and possibly other varnish components) produces quite considerable quantities of copper soaps, particularly when both the cuprous oxide and the rosin contents of the compositions are high. A new component is therefore present in the matrix of the pigmented composition, so that the rate of solution of the latter need not correspond with that of the matrix in the pigmented composition after milling (*see also* p. 365).

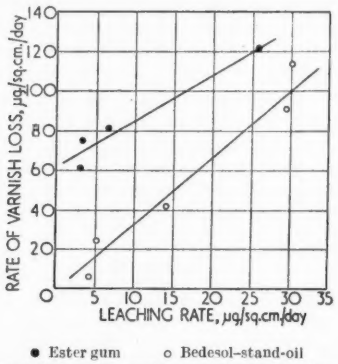

Fig. 1—Leaching rate and varnish losses for compositions with constant copper content and variable matrix

THE MATRIX IN THE LATER STAGES OF LEACHING

In the later stages of soaking a number of complicating factors may contribute to the copper-leaching rate. There is an accumulation of an inert residue of binder materials (probably with some bound rosin) on the surface of many compositions and this, together with the inert pigment, forms a residual skeleton over the surface. There may also be precipitation of insoluble material, particularly of magnesium and calcium soaps, within this residual skeleton ; such a deposition has been demonstrated with unpigmented varnishes during the later stages of immersion.[1] Deposition of insoluble copper salts within this skeletal layer may take place and the intrinsic rate of solution of the matrix may vary with time as a result of changes taking place within the unattacked matrix over an extended period ; processes such as progressive polymerization and oxidation may contribute to such changes. All these processes would tend to reduce the leaching rate. The presence of basic copper salts

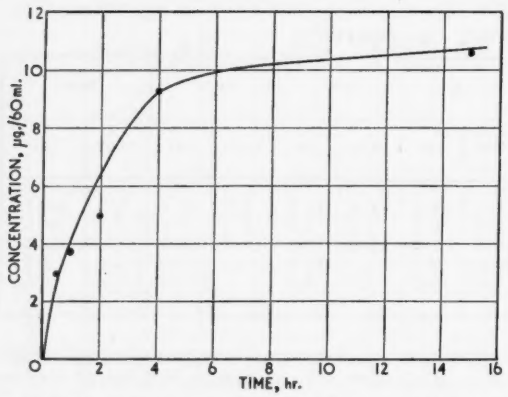

Fig. 2—Time/concentration curve for copper rosinate

deposited within the residual matrix is not to be doubted in many compositions, but the green appearance of many compositions after long soaking is often wrongly ascribed to such basic copper compounds : the green colour is largely due to copper soaps as is clear from the fact that soaking the slides in dilute acid, which would dissolve basic copper salts, hardly affects the colour, and that the green substance is largely soluble in organic solvents. Three compositions containing varying cuprous oxide contents (36, 42, and 48%), but with the same varnish formulation, had steady leaching rates proportional to their copper contents, but after 357 days' soaking, in spite of their different copper content, they had all reached approximately the same leaching rate, namely, 6·9, 7·2, and 6·4 µg./sq. cm./day. After removing some of the green-coloured surface skeletal residue by careful scraping, the slides were re-soaked and within one day the leaching rates were 14·9, 23·9, and 20·7 ; after a further 88 days' soaking the leaching rate had dropped to the previous low value established after 357 days. It is, of course, possible that under these conditions a new steady state may be set up in

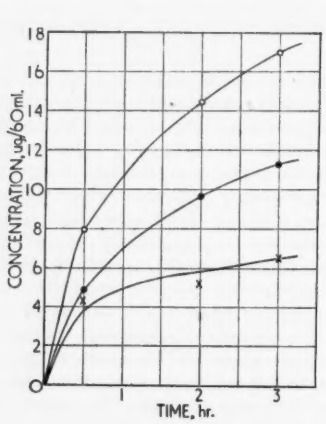

Fig. 3—Time/concentration curves for a number of compositions with variable copper content and matrix composition in late stages of soaking (250 days)

which the values of L_1 and L_2 (equation (1)) are different in the later stages of soaking and give rise to a different leaching rate, but in many of the compositions the leaching rate after 185 days had fallen to a value independent of the formulation, as shown in Table I. This indicated that factors other than those determining the steady leaching rate control the loss of copper. In the late stages, particularly if a thick skeletal residue containing precipitated rosin soaps and insoluble copper compounds has been built up, diffusion processes become the limiting factor in the loss of copper. On ships, mechanical erosion may tend to prevent accumulation of some of these products so that the steady leaching is maintained for longer periods.

The exact contribution of the three sources of copper is difficult to assess from leaching-rate work alone, but that the copper soaps and basic copper salts do contribute to late-stage leaching rates has been shown indirectly. Thus, in the leaching test as ordinarily conducted, there is no retardation of the rate of solution of the cuprous oxide by the accumulation of products in the leaching bath, but if a substance much less soluble than cuprous oxide is used as the toxic pigment then the leaching rate may be retarded by such an accumulation.[3] Such a retardation has been demonstrated when compositions containing cupric carbonate or mercury oxide are leached. It would seem reasonable to suggest that in these later stages comparatively insoluble compounds are contributing to the observed leaching rates and that copper soaps could be responsible as indicated in Fig. 2, which shows a similar concentration/time curve obtained using a solvent-deposited film of commercial copper resinate. Figure 3 shows a number of concentration/time curves using slides from a series that had been soaked for a long period ; a retardation of the leaching rate takes place within the 2-hr. standard test period. How far this vitiates any deductions based on leaching-rate determinations regarding the anti-fouling performance is not clear ; if the copper soap were as poisonous as ionic copper then the effect would be to underestimate the performance on the basis of a leaching-rate determination at these late stages.

AVOIDANCE OF LOW LATE-STAGE LEACHING

Since one of the major factors contributing to the drop in leaching rate with long soaking is the building up of a skeletal residue, which is dependent upon the type of binder used to reduce the leaching rate of the matrix, modifications in the character of the binder are necessary to overcome the low leaching rate. To decrease the structural stability of the non-rosin part of the matrix the amount of liquid plasticizers has been increased at the expense of solid non-reactive resins. In such compositions, once the rosin has

Table II

LEACHING RATE AND VARIOUS BINDERS

Composition	Binder		Leaching rate at days soaking, µg./sq .cm./day					
	Beck resin	Methyl abietate	3	21	88	122	192	240
1	0·0	10·56	41·9	24·8	28·4	25·2	12·4	12·4
2	5·1	6·00	30·5	14·0	14·0	12·5	10·0	9·9
3	9·6	2·00	26·6	14·1	9·9	6·5	10·4	3·3

dissolved there would seem to be little chance of much residual skeletal formation.

Table II shows the effect of changing the ratio of inert rosin to liquid plasticizer in a series of compositions with the same copper content (48% Cu_2O) and the same proportion of rosin to matrix. The second composition could be considered a very promising anti-fouling formulation.

Figure 4 shows the leaching rate of a high-copper composition based on rosin, a Beck resin, and moderate quantities of methyl abietate. After a high initial leaching rate, a very adequate anti-fouling performance could be expected for 300 days from such a composition.

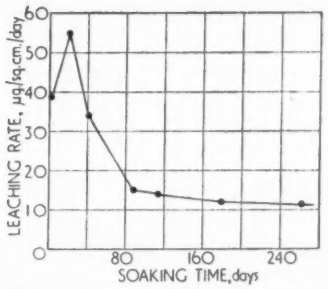

Fig. 4—Leaching rate of composition containing liquid plasticizer

EFFECT OF SOME OTHER BINDERS

In addition to the tests with compositions based on the more common resins referred to above, a limited number of compositions has been prepared using Alloprene (a chlorinated rubber), Lustron (a polystyrene), and a series of Arochlors (chlorinated diphenyls). The Arochlor compositions were made up in the usual way with naphtha. The Alloprene and Lustron compositions were prepared in two stages using xylol as the solvent : all ingredients other than the polymers were milled for six hours, and the polymer, in solution or suspension, was then added and the composition given a further six hours' milling. All the compositions had a small quantity of methyl abietate (2·37% dry weight) and all had a high copper content (48%). The rosin/binder proportion ranged from 7/1 to 1/1. The leaching rates are shown in Table III.

With most of these compositions wide changes of rosin/binder ratio have very little effect on the subsequent leaching rate. The reason for this difference in their behaviour compared with that of the Bedesol/stand-oil and other resin binders has not been fully investigated. However, since the leaching rate is little changed by large increases in the proportion of

Table III

LEACHING RATE FOR VARIOUS ROSIN/BINDER RATIOS

	Soaking Time, days	Rosin in Matrix, %						
		87·5	83·3	75·0	71·4	66·6	60·0	50·0
Alloprene	10	119·1	118·7	123·8	96·0	87·6	14·2	9·5
	31	17·4	22·0	24·1	27·6	23·6	29·1	14·5
	92	7·0	8·7	9·1	9·5	10·2	12·7	9·6
	189	7·1	7·3	10·1	8·6	7·3	8·8	5·4
Lustron	10	109·6	101·2	47·9	48·8	40·7	34·6	30·8
	31	18·1	21·6	19·1	22·5	23·3	23·5	12·5
	92	10·0	11·8	6·2	8·5	11·4	9·9	7·0
	189	8·2	9·9	5·7	5·6	7·1	7·1	4·4
Arochlor (i)	10	84·9	73·5	82·7	63·3	54·3	49·4	15·3
	31	44·9	43·1	44·9	35·6	38·7	35·8	21·4
	92	21·2	19·8	19·3	18·9	19·9	19·6	13·6
	189	15·1	13·4	15·8	12·0	14·6	13·3	6·6
Arochlor (ii)	10	93·8	98·4	80·3	73·5	79·5	61·1	39·9
	31	45·6	42·1	41·5	39·8	34·1	32·9	30·5
	92	18·3	17·4	21·3	19·3	18·7	14·9	10·2
	189	11·7	11·8	12·2	10·5	10·1	9·5	7·3
Arochlor (iii)	10	96·3	70·5	72·3	48·7	25·7	26·0	10·4
	31	39·3	36·4	31·7	31·7	33·9	24·3	20·3
	92	21·4	14·3	10·8	11·9	12·2	11·4	11·9
	189	13·1	8·7	8·6	8·2	8·4	8·1	5·0
Arochlor (iv)	10	71·1	84·3	58·7	55·7	32·5	14·7	6·1
	31	37·1	34·2	26·6	26·2	15·2	8·8	6·2
	92	18·3	13·6	13·5	13·7	12·3	9·7	5·1
	189	18·9	15·0	12·0	8·8	8·6	7·3	6·3

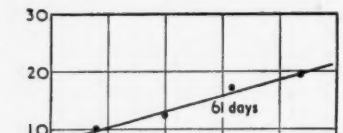

Fig. 5—Relation between leaching rate and cuprous oxide content (rosin/binder ratio 3/1)

binder to rosin there can be no 'protection' of the acid groups in the rosin; this may be attributed to the relative 'inactive' character of the binders. It is also possible that the higher polymers separate out as the composition dries, *i.e.*, they are incompatible with the other matrix components and their behaviour then becomes similar to that of a secondary pigment. With most of these compounds the initial leaching rate was high, *i.e.*, there was a high concentration of surface copper. With the xylol compositions (Lustron and Alloprene binders) this may be caused by a high rate of evaporation of solvent on painting out, with a consequent accumulation of cuprous oxide in the surface and lack of surface varnish. In the naphtha-based compositions, the high initial rate must be due to the absence of varnish film formation as a result of the physical properties of the composition.

Although rather expensive, these materials deserve further investigation, since they may be incorporated over a wide range of concentration to modify any desirable physical properties of the composition, without affecting the leaching rate to any marked extent. Because some of the Arochlors are liquid and others are solids a judicious combination might include the advantage of liquid plasticizers in preventing residual matrix accumulation (*see* p. 361). From the paint technological standpoint these compositions were poor because they settled badly, but an appropriate inert filler could be used to overcome this.

EFFECT OF PIGMENTS

Toxic Pigment–Cuprous Oxide

Equation (1) (*see* p. 360) has been tested experimentally using a series of varnishes and the copper-leaching rate at any given soaking period (except in the later stages) has been found to be proportional to the cuprous oxide content if the total matrix content remains constant. Typical results are given in Fig. 5 for a series of compositions based on cuprous oxide, red oxide of iron, rosin, and Bedesol/stand-oil.

Inert Pigment

The quantity of inert pigment should, within wide limits, have little effect on the leaching rate unless the pigment volume approaches or exceeds that for some continuous contact throughout the film.[11] Also, the leaching rate should be unaffected by the type of pigment. Little work has been done on variations in the type of pigment, but numerous results have been obtained with variable quantities of the standard ferric oxide pigment.

In Table IV the mean leaching rates over several periods of soaking are given for two series of compositions, the second with double the cuprous oxide content of the first, and with a higher rosin/binder ratio and consequently a greater leaching rate. The filler is shown to have no significant effect on the leaching rate even though the filler content is doubled. In all cases, of course, the filler was increased at the expense of the medium, the rosin/binder ratio being maintained constant for each series.

The effect of substituting the iron oxide by three other common fillers is shown in Table V. Since the type as well as the quantity of filler has little effect on the leaching rate, it can be selected so as to confer on the composition such desirable properties as flow, ease of application, and anti-settling, without affecting the anti-fouling performance. This also means that in the experimental stages in the investigation of anti-fouling compositions attention can be concentrated on their anti-fouling behaviour leaving their physical properties to be adjusted in a later-stage investigation when the promising formulations have been selected. For example, although few settling troubles have been experienced with the ferric oxide, cuprous oxide, and rosin–Bedesol–stand-oil compositions, some of the Arochlor and Lustron compositions settled very badly; it is anticipated that this could be readily eliminated by the choice of a more suitable inert filler. In addition, it should be possible to use a corrosion-inhibiting secondary

Table IV

LEACHING RATE AND VARIABLE INERT PIGMENT

Composition	Formulation	Fe_2O_3, %	Mean leaching rate at days soaking, μg./sq. cm./day 29–86	86–146	146–205
1	R/B=3/1	31·1	4·8	6·2	5·2
2	Cu_2O=	38·8	4·1	7·3	6·3
3	15·5%	46·6	7·3	8·7	6·8
A	R/B=2·5/1	15·5	11·2	12·3	9·0
B	Cu_2O=	23·3	5·5	9·2	8·5
C	31·0%	31·0	9·3	12·6	8·1

Table V

EFFECT OF INERT FILLER ON LEACHING RATE

Soaking Time, days	Fe_2O_3	Micaceous Iron Oxide	Talc	Kaolin
3	16·3	15·2	16·8	14·6
10	8·6	8·3	8·7	7·6
19	10·1	8·4	10·0	5·7
28	5·3	6·7	5·7	5·7
68	3·2	3·3	2·9	2·9
84	4·4	4·3	3·7	3·7
122	5·3	4·1	3·6	3·6

pigment without affecting the anti-fouling performance, and this may become particularly important if the more efficient high cuprous oxide compositions are to be used : it is, of course, essential that the pigment should have no effect on the leaching process.

EFFECT OF OTHER FACTORS

Milling Time

The interaction of rosin and the cuprous oxide in the milling process and the effect on the leaching rate have already been stressed.[1] Two further examples are given in Table VI, which substantiate the previous results. In the high cuprous oxide composition the milling time had little effect on the subsequent leaching rate : in the low copper compositions, the leaching rates were higher with the two shorter milling times, but the longer milling times appeared to have little effect on the leaching rate.

These results suggest that with high-rosin, low-copper compositions (and it should be remembered that with low copper contents a high proportion of rosin in the varnish is the only way of obtaining a satisfactory leaching rate) the production of copper soaps proceeds for a long time during milling, whereas saturation or perhaps complete removal of the rosin may take place when the rosin content is low and the cuprous oxide content high. Milling time should therefore be carefully controlled, in order to obtain similar results, and the milling in commercial batches should be comparable to that in the experimental batches. However, in comparing such batches the actual time of milling is only one of many variables ; other factors in the milling process have to be considered when the scale of the preparation is changed. A composition which has proved satisfactory in small-scale preparations should therefore be prepared under full-scale conditions and subjected to test.

Storage Time

The continued reaction of cuprous oxide and the medium, on storage, has already been considered in the earlier paper on the production of copper soaps.[1] Table VII gives a further set of results ; the compositions were all based on a rosin–Bedesol medium with constant amount of cuprous oxide. The first leaching rates were taken after 7 days and the second after 200 days. The results show that storage has affected the leaching rate and has turned some compositions, which would have been anti-fouling for 120 days, into non-effective compositions. After storing for 200 days there is little difference in the behaviour of most of the compositions, which suggests that the matrix has changed.

Table VI

LEACHING RATE (57 DAYS) AND MILLING TIME

Milling time, hr.		½	2	6	12	24
Leaching rate, μg./sq. cm./day	48% Cu_2O R/B=2·5/1	4·8	5·3	3·3	4·4	...
	18% Cu_2O R/B=5/1	22·7	20·3	10·6	13·3	11·6

Table VII

LEACHING RATE AND STORAGE
(Constant Cu_2O)

Time after Preparation, days	Rosin/Binder Ratio	Leaching rate at days soaking, μg./sq. cm. day 10	50	120
7	10/1	53·9	14·9	6·7
	7/1	53·9	14·6	12·6
	5/1	48·4	12·7	12·6
	4/1	41·9	16·7	5·6
	3/1	26·6	17·6	8·6
	1·5/1	4·4	14·5	6·6
200	10/1	21·0	5·5	4·0
	7/1	11·6	7·5	5·7
	5/1	15·9	4·5	3·2
	4/1	6·5	4·2	3·6
	3/1	4·7	3·0	3·9
	1·5/1	2·9	0·8	2·0

Table VIII

LEACHING RATE AND STORAGE
(Cu_2O 48%, Rosin/binder ratio 1·5/1)

Storage, days	Leaching rate at days soaking, μg./sq. cm./day 10	60	141	200
12	28·7	19·1	10·4	7·5
150	19·8	14·0	11·4	5·1

The effect of storage, like that of milling time, is more likely to be important with compositions of low to moderate copper and high rosin content, in which reaction may continue for a long time. Table VIII shows the leaching rate for a high cuprous oxide, low rosin composition (Cu_2 48%, 1·5/1 rosin/binder) after 12 and 150 days' storage.

Figure 6 shows the relation between the change in leaching rate on storage and the percentage of rosin in a series of compositions, first painted a few days after milling and then after being stored 200 days. (The original series had been tank-soaked and the repeats were therefore treated in the same way.) The results confirm that the change in leaching rate is greater in compositions containing large proportions of rosin ; this has also been confirmed by raft tests. That interaction of varnish and pigment or changes accelerated by contact with the pigment in the varnish is responsible, has been shown by comparing the leaching rates of compositions prepared with the fresh varnish and with varnish which had been stored

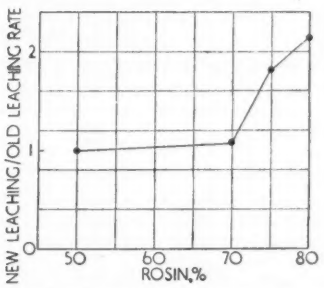

Fig. 6—Effect of ageing on leaching rate showing greater effect of ageing with compositions containing a high proportion of rosin

Table IX

LEACHING RATE AND UNDERCOAT

Surface	Leaching rate at days soaking, μg./sq. cm./day 5	36	98	168	217	290
Ground Glass	2·9	3·8	9·9	14·0	8·7	3·5
A.C.(1)	2·5	3·3	7·3	15·0	9·6	2·0
A.C.(2)	3·3	3·2	6·8	12·2	9·2	2·9

for periods comparable with those required to reduce the leaching rate in the complete composition, when stored. The leaching rates were not significantly different, indicating that contact of pigment with varnish during storage plays an essential part in the reduction of leaching rate on storage. It has not, however, been possible to reproduce this reduction in leaching rate by partial replacement of the rosin by commercial copper rosinate : only a small reduction in the leaching rate was obtained, which suggests that the reactions on storage or milling are more complex than the simple neutralization of the rosin acids.

Effect of the Undercoat

If the overall behaviour of the paint, anti-fouling performance, blistering, rusting, and so on, is in question it is necessary to consider the paint system as a whole, but the undercoat is unlikely to affect the anti-fouling behaviour in a strict sense, *i.e.*, its capacity to prevent settlement, since the leaching rate is dependent only on a water–anti-fouling paint interface reaction. A few experiments, with a very limited range of combinations, support this suggestion. The leaching rates of a moderate cuprous oxide composition applied to ground glass and over two different undercoats, one a commercial preparation and one an experimental composition used frequently in this work, are compared in Table IX. There is no significant difference in leaching rates.

When the behaviour of the system as a whole is in question the relation between the two coats must, of course, be taken into account. Consideration must then be given to both the physical and the chemical compatibility of the two compositions and the 'keying' of the two coats, the possibility of solvent action of the anti-fouling coat on the undercoat, and the working up of materials (such as is well known with bitumen) into the anti-fouling coat must all be considered. In addition, the protection given by the undercoat may have to be related to the formulation of the anti-fouling composition : thus a high-copper composition may tend, with a thin or poorly protecting undercoat, to give rise to blistering, wear, and corrosion under circumstances in which such an undercoat would be completely adequate with low-copper-containing anti-fouling compositions.[12]

Table XI

RELATION BETWEEN SPREADING RATE AND LIFE

Film No.	Thickness, μ	Copper, mg./sq. cm.	Copper lost at days soaking, % 80	98	200	257	357
0	26	3·15	69	95	...	...	...
1	60	7·32	44	...	80	86	93
2	96	10·96	28	...	54	61	74

LEACHING RATE, FILM THICKNESS, AND ANTI-FOULING PERFORMANCE

If the leaching process is dependent only upon the factors already discussed then the leaching rate should be independent of the thickness of the coating. Table X gives mean spreading rates and mean leaching rates over a long perod for four different compositions, applied at three different thicknesses ; the application was made by a doctor-blade technique. The compositions were exposed on test panels at three different spreading rates (about 10, 16, and 20 g./sq. ft.). The fouling history was similar for the three spreading rates for all the compositions, as would be expected from their leaching rates : all were fouled with barnacles after about 178 days' exposure. Except for some differences in the early stages the leaching rate is independent of the film thickness. Raft tests confirm these results.

LIFE OF COMPOSITION AND FILM THICKNESS

Since the leaching rate determines the anti-fouling action, it should be possible from a knowledge of its value and from the cuprous oxide content of the composition, together with the spreading rate, to predict the effective life of the composition. If a moderately steady leaching rate were maintained, the life of the composition should be directly proportional to the spreading rate at a given cuprous oxide content, and proportional to the cuprous oxide content at a given spreading rate. However, a fall in the leaching rate frequently takes place so that the full copper content is never used (*see* Table I) and some of the factors that may lead to this locking up of the cuprous oxide

Table X

LEACHING RATE AND FILM THICKNESS*

Composition		1			2			3		
Dry Weight per Slide, g.		0·0924	0·1526	0·2430	0·0916	0·1657	0·2954	0·0797	0·1576	0·2828
Soaking time, days	3	53·6	52·6	49·2	66·6	58·7	55·8	69·0	71·2	67·2
	25	37·9	35·7	40·2	48·7	46·2	53·0	43·2	33·9	47·1
	72	10·7	11·0	11·3	11·8	14·5	15·7	13·0	15·6	15·0
	118	5·8	8·5	10·5	11·1	13·0	9·3	9·5	12·1	12·8
	180	7·4	8·2	9·1	8·1	11·1	7·4	3·9	8·3	7·9
	264	7·4	7·9	9·2	5·2	8·3	10·9	4·7	7·4	6·3

* Figures are the means of duplicate slides

have already been discussed. If such a gross change in leaching rate is avoided by competent formulation, then the expected relation between spreading rate and life is found. Table XI shows results obtained for a composition,* whose leaching rate did not fall, based on copper rosinate and cuprous oxide with no inert filler. The copper contents and the percentages of copper lost after soaking (as estimated by integration of the leaching-rate graph) are given. The life of the thin film 0, is about 90 days and that of the second thickness about 200 days, whilst the third thickness has not been exhausted nor has the leaching rate dropped below 10 μg./sq. cm./day at 357 days. Film 1 with a high spreading rate of just over twice that of film 0 has rather more than twice its life: this excess of life over that expected is attributed partly to the relative importance of the high initial leaching rates, since a large wastage in this way, before the steady state is established, will have a proportionately greater effect on a thin film than on a thick one.

Raft tests substantiate these results: no actual controls were put out for this series but in other exposures of the same composition (different batches) an estimated raft life of 150 days at a spreading rate of 10·8 g./sq. ft. was found, whilst an exposure of 20·0 g./sq. ft. was showing incipient fouling at 336 days, but was not definitely rated as fouled at this time when they were withdrawn. The first of these exposures is rather heavier than film 0 (7·8 g./sq. ft.) and the second rather heavier than film 1 (18·2 g./sq. ft.); the results, therefore, check well with those of the leaching-rate experiments.

CONCLUSIONS

An examination of the leaching-rate technique has shown that a simple model of the leaching-rate process is fundamentally sound, although to allow for the effect of all variables certain modifications are necessary.

The leaching rate is shown to be primarily a function of the poison content and the matrix composition. Complications arise through the building up of a residual matrix. This process, which locks up residual cuprous oxide, may be eliminated by increasing the amount of liquid plasticizer at the expense of solid non-reactive resins.

Xylol- and naphtha-based compositions may be used to modify any physical properties of the composition without affecting the leaching rate.

The type and quantity of filler used have little effect on the leaching rate and can therefore be selected to confer the desired properties on an anti-fouling composition.

Other factors such as milling and storage times may affect the leaching-rate process.

* Formulated by Dr. H. W. Harvey

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Radiographic Techniques for Examining Steel Castings

By the Non-Destructive Testing Sub-Committee

SYNOPSIS

This report describes a series of radiographs of a set of steel plates of thicknesses varying from ⅞ to 8 in. Different radiographic techniques were used, including gamma rays as well as X-rays of from 110–1000 kV. with lead and tungstate screens, and their relative merits for each thickness of steel are determined.

THIS report describes an investigation carried out by members of the Non-Destructive Testing Sub-Committee into the relative merits of a number of radiographic techniques suitable for use on steel castings. The techniques examined are listed below, and whilst they do not represent all the possibilities, it is considered that they cover most of the methods likely to be used in general industrial radiography.

Procedure

For the investigation, four cast-steel plates were obtained, each 15 × 12 in., with the main faces machined, the finished plate thicknesses being ⅞, 2, 3, and 4 in. respectively. All the plates were manufac-

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Table I

CLASSIFICATION OF RADIOGRAPHIC TECHNIQUES

Technique	Radiation	Screens	Film	⅞-in. Plate		2-in. Plate		3-in. Plate		4-in. Plate		5-in. Plate		6-in. Plate		8-in. Plate	
				Contrast	Definition	Contrast	Definition	Contrast	Definition	Contrast	Definition	Contrast	Definition	Contrast	Definition	Contrast	Definition
a	110-kV. X-rays	tungstate	salt-screen type	*A*	*B*												
b	200-kV. ,,	lead	Crystallex	*B*	*A*	*A*	*A*										
c	250-kV. ,,	tungstate	Crystallex	...	...	*C*	*C*	*C*	*D*								
d	250-kV. ,,	tungstate	salt-screen type	*D*	*D*	*A*	*B*	*A*	*A*								
e	400-kV. ,,	lead	Crystallex	*C*	*B*	*B*	*F*	*B*	*B*								
f	400-kV. ,,	lead	Industrex *D*	...	...	...	...	*F*	*F*								
g	400-kV. ,,	tungstate	salt-screen type	*E*	*E*	*E*	*C*	*C*	*C*	*C*	*E*	*A*	*B*	*A*	*B*	...	*A*
h	1000-kV. ,,	lead	Crystallex	...	...	...	...	*G*	*G*	*A*	*A*	*C*	*A*	*C*	*C*	...	...
j	1000-kV. ,,	tungstate	salt-screen type	*E*	*E*	*C*	*C*	*C*	*D*	*B*	*C*	*A*	*C*	*A*	*A*	*A*	...
k	Gamma rays from radium or radon	lead	Crystallex	*G*	*E*	*C*	*C*	*C*	*G*	*C*	*D*	*C*	*A*	*C*	*D*	...	...
l		tungstate	salt-screen type	*H*	*H*	*G*	*G*	*G*	*G*								

* This technique was included on the 3-in. plate, as the use of fine-grain film (technique *e*) required a very long exposure time

tured to contain extensive castings defects, consisting principally of 'centre-line' shrinkage, whilst the thinnest plate also contained some sand and slag inclusions. The thicker sections of 5, 6, and 8 in. were built by using the 4-in. plate, which contained the most severe defects, with additional thicknesses of rolled steel.

Radiographs were obtained on each thickness using a number of different radiographic techniques, and an attempt was made to compare their quality.

The techniques investigated were limited to those likely to be suitable for the examination of plates of uniform thickness and some may not be suitable for castings where a rapidly changing section has to be radiographed on one film. To limit the number of techniques investigated, and because tungstate screens are normally employed only when the exposure time would otherwise be too prolonged, it was decided not to use the slower fine-grain tungstate screens, but to confine the investigation to a pair of high-speed screens; fine grain (Crystallex) film was used with the metal screens except where the exposure time for this film would have been too long to be practical.

To simplify comparison of the radiographs, film densities as close as possible to 1·8 for lead-screen techniques and 1·4 for tungstate screens were used in conjunction with the standard processing technique.

To ensure that the definition obtained on the radiographs should be dependent on the film-screen combination and quality of radiation employed, and not on the size of the focal spot of the particular X-ray tube used, the largest possible focus-film distance was used. It was intended originally that all the X-ray exposures should be made with a focus-film distance of 60 in., so that the effect on the definition of using tubes with different focal-spot sizes would be minimized, but it was found necessary in order to keep the exposure times within practicable limits, to reduce the distance to 36 in. for the 6-in. and 8-in. specimens with lead screens and to increase it considerably with tungstate screens at 400 and 1000 kV. on the ⅞-in. and 2-in. plates. The gamma-ray exposures also, were made, as far as possible, with a source-film distance of 60 in., so that the definition obtained on the radiographs was dependent on the film-screen combination used, and not on the geometric conditions. This could not however be effected with the thicker sections and a compromise had to be made between large source-film distances and practical exposure times. Some difficulty was experienced later in comparing the definition on radiographs taken with different source-film distances because of the slight differences in projection of some of the flaws.

A considerable amount of edge-masking of the plates was necessary with the X-ray technique, particularly when tungstate screens were employed. This was not necessary with gamma-ray exposures. The radiographic techniques employed are given in Table I in which the definition and contrast in the radiographs resulting from each technique have been compared. Each specimen thickness has been treated independently, and there is no correlation between one thickness and the next, *e.g.*, letter *A* means that this technique is considered to be the best for that particular thickness; letter *E* signifies that this is

considered to be the fifth best method. There is no quantitative significance in the lettering; a change from one letter to the next indicates only that one radiograph is better than the other.

The defects in the 4-in. plate when built up to 8 in. of steel by the addition of another 4 in. between the defects and the film were not sufficiently pronounced to produce radiographs with enough detail to enable comparisons of the four possible techniques to be made on the 8-in. plate. Furthermore, 8 in. approached the practical limit of the 1000-kV. set, hence the results given for this thickness are tentative.

Detailed Results

$\frac{7}{8}$-*in. Plate*—Eight different techniques were compared for this thickness and the radiographs varied considerably in quality. Only the technique *l* could be regarded as useless, but with techniques other than *a*, *b*, *d*, and *e*, some fine detail became indiscernible. These four may be considered satisfactory techniques for this thickness, although there was a considerable variation in quality between them. Some dendritic structure associated with shrinkage in the plate could be seen only with technique *b*; with this thickness it is a greater advantage to have the superior definition obtainable with fine-grain film (technique *b*), than to have a slight increase in contrast with poorer definition (technique *a*).

Although some very small defects were lost and the fine structure of the shrinkage was not discernible, the main defects in this plate were still shown with techniques *g*, *h*, *k*, and for much radiography of cast steel of this thickness such techniques would be satisfactory.

2-*in. Plate*—Seven different techniques were used, but the range of quality in the radiographs was much smaller than on the $\frac{7}{8}$-in. plate. With technique *l* only the rough outline of the larger defects could be decided; this technique would be suitable only for the detection of very gross defects but any of the other techniques would be suitable for casting examination of this thickness.

Some shallow defects which were shown with techniques *c* and *e* were not discernible with technique *d*, and for the highest-quality radiographs either *c* or *e* should be used. There is little to choose between these two and, provided that fine-grain film with metal screens is used, it would appear that with this thickness of specimen the kilovoltage employed is not critical.

3-*in. Plate*—The defects in this plate were not so varied in size as in the $\frac{7}{8}$-in. and 2-in. plates and were relatively shallow. Eight techniques were tried, and three, *g*, *j*, and *l*, were found to be unsatisfactory; the extent of the defective area was not clearly defined although there were some indications of the worst defects.

The remaining techniques, *d*, *e*, *f*, *h*, and *k* may all be considered satisfactory; there was only a small difference between them in the contrast obtained, but there was a progressive deterioration of the definition, most noticeable with techniques *d*, *h*, and *k*, which made it more difficult to recognize the nature of the defects. Techniques *e* and *f*, therefore, produced the highest-quality radiographs.

4-*in. Plate*—On the thicker plates the number of possible techniques was more limited, and five different methods of examination were tried.

All five showed most of the defects, and would be satisfactory for many castings, but there was a considerable difference in radiographic quality between the two radiographs taken with lead-screen techniques *h* and *k*, and those with salt-screen techniques *g*, *j*, and *l*. These latter did not show some of the more shallow defects, and the poorer definition made interpretation very difficult.

5-*in. Plate*—Radiographs on this thickness were possible only with 1000-kV. X-rays and with gamma-rays. There was a considerable difference in quality between the radiographs taken with lead-screen techniques *h* and *k* and those with salt-screen techniques *j* and *l*, these latter showing the larger but not the smaller defects. There was little apparent difference between 1000-kV. X-rays and gamma-rays from radon for this thickness.

6-*in. Plate*—The defects in this plate were relatively shallow and assessment of the radiographs was not very easy. The lead-screen radiographs, techniques *h* and *k*, were considerably better than the salt-screen techniques *l* and *j*, although these latter showed most of the defects. All four techniques would probably be suitable for much casting radiography of this thickness, although with *l* and *j* there might be some difficulty in deciding the exact nature of the defects by reason of the poor definition.

Gamma-rays gave a slightly better-quality radiograph than 1000-kV. X-rays, but the differences were not great.

8-*in. Plate*—The defects were too shallow to enable a satisfactory assessment of the different techniques to be made; apparently this thickness was beyond the practical limit for 1000-kV. X-rays and the only technique investigated that was suitable used gamma-rays obtained from radon.

General Conclusions

The results suggest that good definition on a radiograph is of more importance than high contrast when they are alternative, although they are not necessarily independent. Since it is necessary to recognize the nature of a defect as well as its presence, it was concluded that on the thinner plates, the use of fine-grain film at the higher kilovoltage yielded better radiographs than tungstate screens.

The use of tungstate screens with 1000-kV. X-rays and with gamma-rays has apparently little purpose; the screens have only a low intensifying factor with very hard radiation and the results are always inferior to those obtained with lead screens.

Gamma-rays from radon or radium and 1000-kV. X-rays differ little for up to 5 in. of steel but there are indications that gamma-rays will give better results with greater thicknesses.

The techniques investigated do not cover all the possibilities but it is considered that the assessment of those listed will serve a useful purpose. A radiograph should always be taken by the best practicable technique, and it is hoped that this report will give some guidance on the loss in quality to be expected when techniques other than the best are used.

A Method of Simulating the Oil-Cooling of Steel Bars

By W. Steven, Ph.D., A.I.M., and G. Mayer, B.Sc.

SYNOPSIS

Cooling curves determined from temperature measurements taken at several positions in bars of up to 5¾ in. diameter quenched in oil have been compared with the air-cooling curves of bars up to 0·8 in. diameter. It is shown that the cooling of a 1–6 in. dia. oil-quenched bar, over the temperature range within which transformation to structures other than martensite is likely to occur, can be closely simulated by air-cooling a bar of appropriate size between 0·052 in. and 0·890 in. diameter.

A close equivalence relationship has been established between the cooling curves of bars quenched in oil and the cooling curves derived at points along the length of an end-quenched Jominy test specimen, based on a comparison of the curves at temperatures in the transformation range below about 700° C.

The experimentally determined cooling curves were not in good agreement with curves calculated from the Tables published by Russell, but the differences between the cooling curves for the axial and near-surface positions of 2–6 in. diameter bars cooled in air agreed, over the temperature range 800–500° C., with the 'time-lag' equation used by Jackson and his collaborators.

Introduction

THE purpose of this work was to find a simple laboratory method of cooling small bars of steel under conditions which simulate those developed when large bars are quenched in oil. It is often convenient to study steels produced in a small laboratory furnace, but this method restricts the amount of each steel available, and usually precludes assessing the behaviour of the steel when heat-treated in sizes much greater than 2 in. dia. As was recently demonstrated by Crafts and Lamont[1] in their study of a series of B.S. En steels, useful information can be obtained from the Jominy end-quench test,[2] which requires bars of only 1 in. dia. The usefulness of this test is restricted, however, because it provides only a thin disc of material representative of each cooling rate. The use of the Jominy test has also been criticized because of differences between the cooling curves of an end-quenched bar and those of normally quenched bars. This aspect of the Jominy test is discussed on p. 375.

It was thought possible that small bars cooled freely in air might follow the required oil-cooling schedules with sufficient accuracy. Although it was appreciated that the air-cooling curves would not match the oil-cooling curves at all temperatures, this was not considered essential, for the following reasons. Most of the transformations that occur in steel during oil-quenching occur at temperatures below about 700° C., and differences in cooling rates above this temperature will have little effect on the course of transformation at lower temperatures. It might be argued from the propositions advanced by Scheil and others[3–5] that deviations at temperatures above 700° C. would alter the temperature at which transformation starts, but at these temperatures the periods of incubation for isothermal transformation are generally relatively great, and the effect will therefore be small for most steels. Deviations from the form of the oil-cooling curve to be simulated are also permissible at temperatures below about 300° C., since most alloy steels transform to martensite below this temperature and the progress of the reaction is not affected by cooling rate.

Accordingly, it would be sufficient to reproduce the oil-cooling curves accurately only over the temperature range 700–300° C., and it seemed possible to achieve this by air-cooling smaller bars of selected sizes. Such a method of simulating oil-cooling would be experimentally simple, and the amount of each steel required would be restricted. Also, since the temperature gradients developed across the sections of small bars cooled in air are not great, it could be assumed that the whole bar transformed simultaneously and that the structures developed would be representative of one cooling schedule.

To assess the validity of this method, and to establish the equivalence relationship required for its application, it was necessary to compare the cooling curves of a range of bars cooled in oil with those of a range of small bars cooled in air. Accordingly, oil-cooling curves determined for 1–5¾ in. dia. bars were compared with the cooling curves of 0·1–0·8 in. dia. bars allowed to cool freely in air from the same temperature. The air-cooling curves of the 1–5¾ in. dia. bars were not required for the present investigation, but were determined for future use.

The experimentally determined cooling curves were checked for the accuracy with which they conformed to the curves calculated by the method outlined by Russell[6] and by the time-lag equation used by Jackson and co-workers.[7] The relationship between the cooling curves of bars quenched in oil and the cooling curves taken at positions along the length of an end-quenched Jominy test specimen was also examined.

DETERMINATION OF COOLING CURVES

The Pt/Pt–10%Rh thermocouples used for temperature measurement were inserted in 0·1-in. dia. flat-ended holes drilled in the bars at right angles to the bar axes. The mid-radius and near surface

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Dr. Steven and Mr. Mayer are on the staff of the Development and Research Department, The Mond Nickel Company, Ltd., Birmingham.

positions ($r/b^* = 0{\cdot}5$ and $0{\cdot}8$, respectively) were reached by drilling from the opposite side of the bar. (Boegehold and Weinman[8] have shown that cooling curves obtained by means of thermocouples positioned in this manner are identical with those obtained from thermocouples inserted in the bars in holes drilled parallel to the bar axes.) The thermocouple junctions were welded to the bars by resistance welding. The individual wires were insulated in the normal manner, and to prevent contamination of the thermocouples by the quenching oil the space around the thermocouple insulation was packed with a mixture of alundum and waterglass and the thermocouple insulation was sealed with a porcelain cement.

The lengths of the 1-in. and 2-in. dia. test bars were made equal to, or greater than, five times the bar diameter, so as to minimize the effects of 'end-cooling.' The lengths of the larger bars were equal to three or four times the diameter, and their ends were insulated with asbestos discs. The bars were austenitized at 840° C., and an arbitrary austenitizing time of 30 min. per inch of diameter was adopted for all tests.

The preliminary tests showed that the loose outer scale, formed on the surfaces of the bars during the first austenitizing treatment after machining, retarded oil-cooling and air-cooling to a greater extent than the more adherent scale formed during subsequent austenitizing treatments. The cooling curves of pre-scaled bars appeared to be more reproducible than those of freshly machined bars, and for this reason all the test bars used for the determination of cooling curves were pre-scaled by preliminary normalizing treatments.

It was necessary to adopt a standard method and rate of stirring the test bars in the quenching oil during the quench, and it proved comparatively easy to obtain satisfactorily reproducible results with manual stirring. The bar was suspended by a hook from a horizontal support placed across the top of the quenching bath, and the test bar, which hung vertically in the oil, was rotated in an orbit of approximately 12 in. dia., at a uniform speed which was checked (by timing with a stop-watch) at frequent intervals during each quench. The standard rate of stirring adopted was 18 r.p.m., and the initial temperature of the quenching oil was in all cases 30° C. The viscosities and flash-points of oil *A*, used for most of the tests, and of oil *B*, used for tests described on p. 372, are as follows :

Temperature, ° C.	Viscosity (Redwood No. 1), sec. Oil *A*	Oil *B*
18	370	280
25	265	200
30	210	150
35	170	120
40	145	95
Closed flash-point :	202° C.	154° C.

For air-cooling, the bars were suspended in mid-air and precautions were taken to exclude extraneous draughts.

A short-period galvanometer was used to measure temperatures, and the time/temperature curves were recorded manually by tracing the path of a narrow beam of light reflected from the galvanometer on to a paper chart, which moved at a constant speed in a direction at right angles to the line of the galvanometer deflection.

Air-cooling and oil-cooling curves were determined for the axial positions of $3\frac{3}{4}$-in., 3-in., 2-in., and 1-in. dia. bars of a B.S. En 25 steel, and for the mid-radius and 'near surface' positions ($r/b = 0{\cdot}5$ and $0{\cdot}8$) of $3\frac{3}{4}$-in., 3-in., and 2-in. dia. bars of the same steel. Additional air- and oil-cooling curves were determined for the axial position of 1-in. and $3\frac{3}{4}$-in. dia. samples of a B.S. En 26 steel, which remained austenitic over greater temperature ranges than the B.S. En 25 steel. Many of the curves were determined in duplicate or triplicate, and the results indicated that the curves were reproducible to within $\pm$ 5° C.

The average air- and oil-cooling curves are shown in Figs. 1 and 2. In these and other diagrams the curves have been discontinued at temperatures slightly above those at which transformation started. Time values for air-cooling were recorded from the moment the bars left the furnace, and those for oil-cooling from the moment the bars were half immersed in the quenching oil.

The air-cooling curves (Fig. 1) of a $5\frac{3}{4}$-in. dia. bar of a B.S. En 30*B* steel were determined using the same procedure as that described for the air-cooling curves of the smaller bars. Because of its size, however, it was necessary to determine the oil-cooling curve of this bar (Fig. 2) in another heat-treatment shop, and some difficulty was encountered in reproducing exactly the details of the quenching procedure which had been adopted as standard. The time taken to transfer the test bar from the furnace to the

* r = distance from bar axis, b = radius of bar.

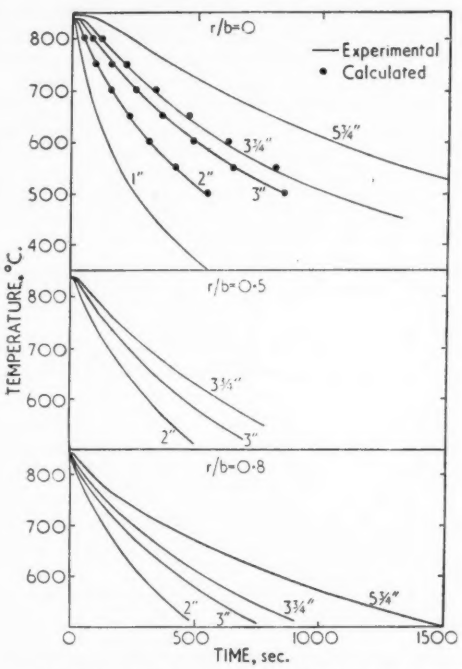

Fig. 1—Experimentally determined air-cooling curves, and points calculated for the $r/b = 0$ position using the 'time-lag' equation

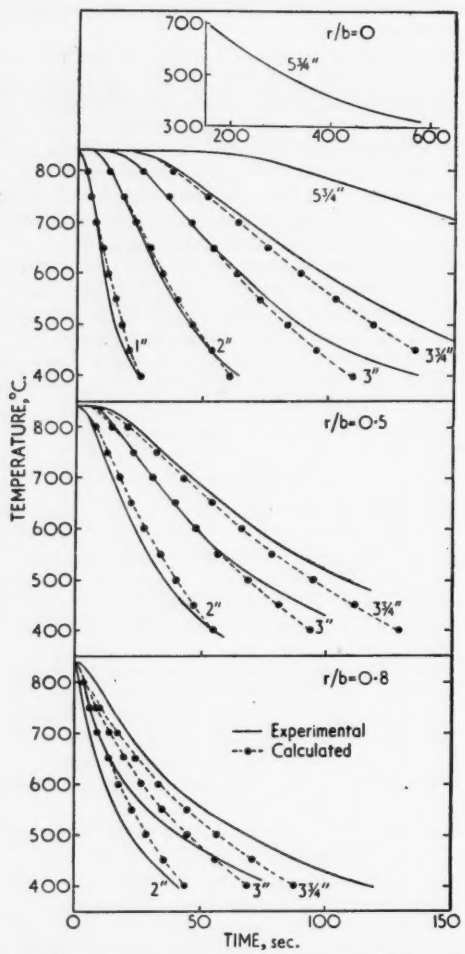

Fig. 2—Experimentally determined oil-cooling curves, and curves calculated by the method outlined by Russell[6]

quenching bath was unavoidably increased from approximately 5 sec. to about 40 sec., and although the standard rate of stirring was reproduced satisfactorily, the physical characteristics of the quenching-oil used (oil *B*, *see* p. 371) were slightly different from those of the quenching oil *A* used previously. The oil-cooling curve of a 3-in. dia. bar quenched in this oil was only slightly different from that determined under the standard conditions.

Samples of a B.S. En 26 steel were used to obtain air-cooling curves of small-diameter bars, and the sizes chosen for test had diameters of 0·1, 0·2, 0·3, 0·4, 0·6, and 0·8 in. It was considered that holes in these bars would significantly upset heat flow, and the thermocouple wires were therefore welded separately to the surfaces of the bars near their mid-lengths. When these bars were withdrawn from the furnace an almost instantaneous temperature drop of approximately 20° C. was observed, similar to the effect observed by Russell and Williamson.[9] The average cooling curves obtained, given in Fig. 3, have therefore been drawn from an ' initial ' temperature of about 820° C. The oil-cooling curves for the axial positions are also given, for comparison with the air-cooling curves of the small-diameter bars.

DISCUSSION OF RESULTS

Equivalence Relationship Between Oil- and Air-Cooling Curves

Comparison of the oil- and air-cooling curves in Fig. 3 shows clearly that it is impossible to simulate closely, at all temperatures, the oil-cooling of a bar by the air-cooling of a smaller bar. If an oil-cooled bar and an air-cooled bar cool at the same rate, at a temperature within the range in which transformations are likely to occur (say 500° C.), the oil-cooled bar will cool appreciably slower at temperatures above about 750° C. For most metallurgical investigations, however, it is sufficient to simulate the required cooling curve closely only over the temperature range 700–300° C., and consideration of the curves showed that a close match between oil-cooling and air-cooling curves over this range was possible.

The criterion of equivalence used to match the two sets of curves was the time taken to cool from 700° to 500° C., as this would be expected to give the closest possible match over the range 700–300° C. Figure 4 indicates the degree of equivalence obtainable. It was not possible to assess the agreement at temperatures below about 400° C., because the experimental curves below this temperature were affected by transformations, but the general trend indicates that the discrepancies, at least above 300° C., are negligible for most purposes. Equivalent bar sizes for the $r/b = 0, 0·5$, and $0·8$ positions are given in Fig. 5.

Theoretical considerations, and the experimental work of French and Klopsch,[10] suggest that if a number of simple shapes such as cubes, plates, cylinders, spheres, etc., have equal volume/surface-area ratios, their centre positions will, if the shapes are quenched under identical conditions, follow the same cooling curves. On this assumption, the air-cooled bar sizes necessary to simulate the oil-cooling of simple shapes other than infinitely long cylinders may be obtained from the upper horizontal scale of Fig. 5.

The equivalence relationship shown in Fig. 5 can be represented with adequate accuracy by the empirical equation :

$$\log D_A = 1·59 \log D_0 + \log b, \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

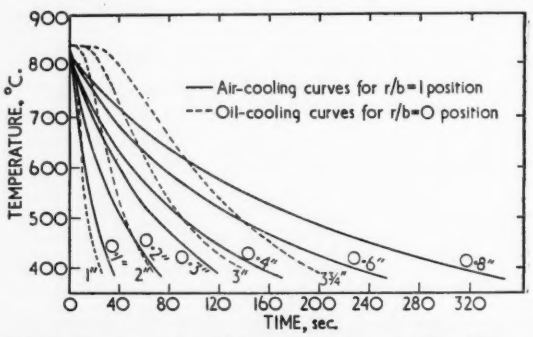

Fig. 3—Comparison of shapes of oil- and air-cooling curves

where D_A is the diameter (in inches) of the bar which must be cooled in air to simulate the oil-cooling of a bar of diameter D_0, and b is a constant which has the values 0·052, 0·045, or 0·036, when the equation is used to derive the equivalent air-cooled sizes for the $r/b = 0$, 0·5, and 0·8 positions, respectively, of oil-quenched bars.

To simulate the oil-cooling curves of the centre of a 6-in. dia. bar it is necessary to air-cool a 0·89-in. dia. bar. This bar size is greater than was originally anticipated, and it was suspected that the rates of cooling (in the relevant temperature range) of different points across the section of a bar of this size might be significantly different, in which case it would not be permissible to assume that the surface cooling curve was representative of the whole section of the bar. To check this possibility, the cooling curves of the axial and surface positions of a 0·8-in. dia. bar of B.S. En 30*B* steel, cooling freely in air from 840° C., were recorded simultaneously and compared ; results were as follows :

Position	Time, sec., to cool from 700° C. to : 600° C.	500° C.	400° C.	350° C.
$r/b = 0$	56	140	268	365
$r/b = 1·0$	56	140	270	366

These results show that the variation of cooling rate across the section of a bar of this size and therefore of any smaller size, can be safely neglected.

Experimental Verification of the Equivalence Relationship

To test the reliability of the proposed method of simulating oil-cooling, the hardness values at the axes of 1–3¾ in. dia. oil-quenched bars of six commercial steels (*see* Table I) were compared with the average hardness values developed across the sections of the equivalent sizes cooled in air. To eliminate, as far as possible, the effects of transverse variations of hardenability, equivalent pairs of bars were machined co-axially from the same 4-in. square billet of each steel. The tests were carried out under the standard conditions for air-cooling and oil-quenching given on p. 371, and the results are illustrated in Fig. 6.

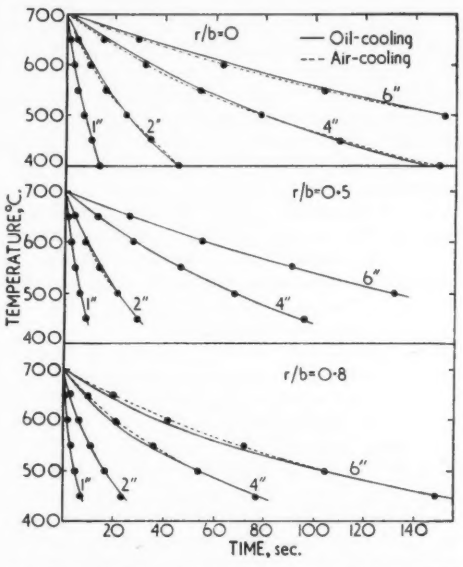

Fig. 4—Comparison (at temperatures below 700° C.) of the oil-cooling curves for the $r/b = 0$, 0·5, and 0·8 positions in 1–6 in. dia. bars, with the air-cooling curves of bars of 'equivalent' size

Table I

ANALYSES OF STEELS USED FOR HARDNESS COMPARISON

Steel No.	Composition, Wt.-% C	Si	Mn	Ni	Cr	Mo
1	0·39	0·24	0·78	0·27	1·10	0·11
2	0·41	0·25	0·61	3·48	0·30	0·12
3	0·36	0·22	0·52	1·52	1·17	0·27
4	0·35	0·22	0·56	1·63	1·07	0·21
5	0·33	0·25	0·58	0·29	1·66	0·42
6	0·33	0·26	1·57	0·20	0·26	0·43

The variations in hardness in the air-cooled bars of each steel are indicated by the shaded areas, and the hardness ranges observed in the oil-quenched bars are superimposed on these bands as vertical lines at the appropriate equivalent positions. The hardness variations observed within each oil-quenched and air-cooled test bar are normal for samples machined from billets of commercial steel. The overall agreement between the two sets of hardness values is satisfactory, and confirms the validity of the equivalence relationship derived from the cooling curves.

Limitation of Equivalence Relationship

Although this method of simulating oil-cooling is useful for many purposes, the sizes required to simulate oil-cooling are not wholly convenient for studying the influence of cooling rate on the mechanical properties of steels. The diameter of the Hounsfield balanced impact test specimen, which is the smallest specimen likely to be used, is 0·3125 in., and an air-cooled bar of

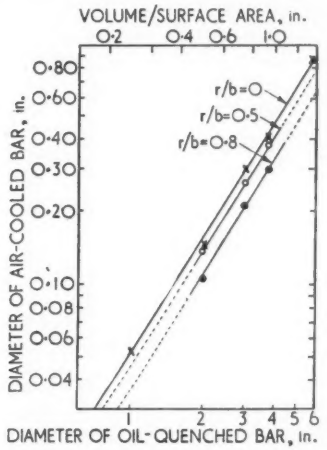

Fig. 5—Equivalent air-cooled bar sizes for the $r/b = 0$, 0·5, and 0·8 positions in oil-quenched bars

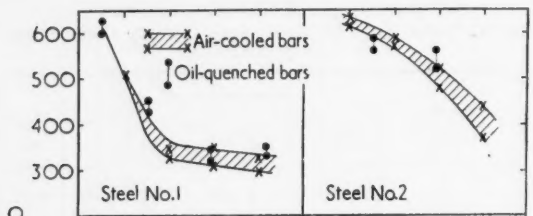

Fig. 6—Comparison of the hardness at the axes of oil-quenched bars with the hardness of the equivalent-sized bars cooled in air

this diameter is equivalent to a 3·1-in. dia. bar cooled in oil. It would not, therefore, be possible to machine specimens from the bars used to simulate the oil-cooling of bars of smaller diameter. A modification of this method, or some alternative, is consequently required for the study of the impact properties of bars of smaller size.

Calculation and Correlation of Cooling Curves

An attempt was made to calculate the oil-cooling curves, using the method described by Russell[6]; the curves obtained are shown in Fig. 2, together with the experimental results. The value of the thermal diffusivity of the steel was assumed to be 0·01 sq. in./sec., and it was found by trial and error that the best overall agreement between calculated and experimental results was obtained using a value of 1·0 in.$^{-1}$ for the quenching intensity h. A measure of agreement between the calculated and experimental curves is apparent, but the nature of the discrepancies suggests that, although satisfactory agreement can be obtained for a restricted range of bar sizes (using a selected value of h), the overall agreement would have been less satisfactory if a wider range of bar sizes had been considered. If an individual h value had been selected to match the cooling curves of each bar size, it would have been necessary to use lower values as the bar size increased. This trend has been observed elsewhere.[11, 12]

Russell[6] has shown that if a cylindrical body of constant diffusivity, initially at a uniform temperature, is heated in a manner such that its surface temperature rises uniformly, then the temperature difference between the surface and the axis, after a certain initial period, is given by the equation :

$$\text{Temperature difference} = \frac{\text{Rate of heating} \times \text{Radius}^2}{4 \times \text{Diffusivity}} \quad (2)$$

This equation can be rewritten in a form which is known as the 'time-lag' equation :

$$\text{'Time-lag'} = \frac{a^2}{4D} \quad \ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots (3$$

where 'time-lag' is the time interval between the surface of the cylinder reaching a given temperature and the centre of the cylinder reaching the same temperature, a is the radius of the bar, and D is the thermal diffusivity of the material. Jackson and his co-workers[7] showed that, although diffusivity is not constant and the rate of temperature rise of the surface is not uniform, equation (3) can be used to derive the time-lag between the surface and the axis of slowly heating bodies, with adequate accuracy for practical methods. For this purpose they defined 'slow heating' as heating such that the rate of change of surface temperature and the mean diffusivity through the mass of steel vary only slightly in a period of time equal to the 'time-lag.'

In view of the success achieved by these investigators with the time-lag equation, it was of interest to see whether it applied to the air-cooling curves determined for the 1–5¾ in. dia. bars used in this investigation. Accordingly, the values of D required to fit equation (3) to the experimental curves for the 5¾-in. dia. bar, over the temperature range 800–500° C., were calculated as follows :

Temperature, ° C.	D
800	0·0085
750	0·0075
700	0·0070
650	0·0068
600	0·0066
550	0·0064
500	0·0064

and these values were used to derive the axial cooling curves of the 2-in., 3-in., and 3¾-in. dia. bars (over the same temperature range) from the corresponding curves for the $r/b = 0{\cdot}8$ position. The good agreement obtained between the experimental and calculated axial cooling curves is shown in Fig. 1, in which the calculated points are superimposed on the experimental curves.

It is expected that the time-lag would reach a maximum value when plotted against temperature. The available data do not extend to sufficiently low temperatures to illustrate this feature clearly, but the trend of the variation of D with temperature is in accordance with this theory.

These values of D are of the order to be expected from the results of Jackson and his co-workers,[7] and are also of the order expected for the diffusivity of steel in the austenitic condition in this particular temperature range.[13] The equation has, however, been applied to cooling conditions very different from those assumed in its derivation, and D has been assumed to vary with temperature. For this application, therefore, the equation should be regarded as empirical, and the D values quoted should be regarded as arbitrary constants rather than as absolute diffusivity values. In view of this, there is no suggestion that the experimental cooling curves conform to those derived on the basis of the assumptions outlined

by Russell in ' Case 2 ' of the paper[6] from which the ideal equation has been taken.

Within the limits of experimental error and the range of bars investigated, there is a linear relationship between the logarithms of cooling times and the logarithms of bar diameter. This is illustrated in Fig. 7, in which the times taken by the axes of oil-quenched bars to cool from 700° C. to a series of lower temperatures have been plotted against bar diameter ; the results indicate that the cooling curves conform to an equation of the type :

$$T - x = y\,d^n, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where T = time to cool to a temperature θ
x = time to cool to 700° C.
y = constant depending on θ
d = bar diameter
n = constant depending on the quenching conditions.

The oil-cooling curves for other bar positions, and the curves for all test positions in the air-cooled bars, also conform to this type of relationship over the range of bar sizes studied. The values of n required to fit the equation to the experimental curves are 1·03 for air-cooling and 1·71 for oil-cooling.

Equation (4) is substantially the same as that used by French and Klopsch,[10] except that they assumed x to be the time to cool to a temperature above 700° C. and used the volume/surface-area ratio as a measure of size to permit the application of the equation to cylindrical bars of finite length and to other simple shapes. Their equation closely fits the experimentally determined oil-cooling curves, but does not fit the air-cooling curves as closely as does equation (4). If x is taken as the time to cool from 825° C., as recommended by these investigators, the value of n is not the same for different test positions in air-cooled bars, and is slightly less than unity for the $r/b = 0{\cdot}8$ position. Accordingly, the lower reference temperature of 700° C. is preferred.

The largest cylindrical bar investigated by French and Klopsch was 2 in. dia. × 8 in. long, and they studied the cooling curves for the centre position only. The present results suggest that equation (4) applies to the curves for several positions in infinitely long 1–6 in. dia. bars cooled in oil or in air.

These logarithmic relationships have proved useful for the correlation and interpolation of the cooling curves. Similar relationships probably apply to the cooling curves of bars quenched in other media or quenched in oil under conditions different from those adopted in this investigation. Consequently, since the relationship is linear, it would be necessary to determine only a few additional cooling curves to derive a correlation between air-cooling and a different set of quenching conditions from that used by the present authors.

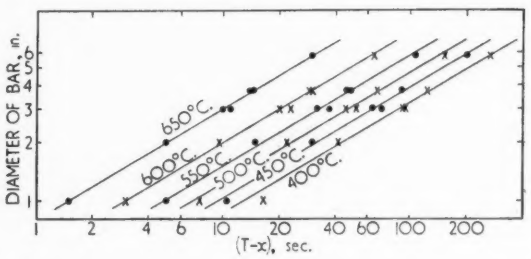

Fig. 7—Logarithmic relationship between cooling times and bar diameters, for the axial position of oil-quenched bars

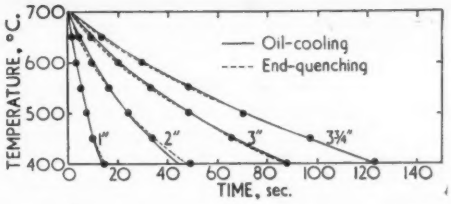

Fig. 8

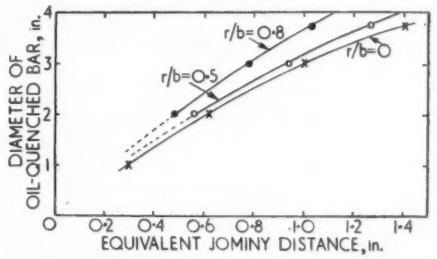

Fig. 9

Fig. 8 — Comparison of cooling curves for oil-quenched bars ($r/b = 0$) with end-quench cooling curves

Fig. 9—Equivalent Jominy distances for the $r/b = 0$, 0·5, and 0·8 positions in oil-quenched bars

Relationship Between Oil-Cooling Curves and the Cooling Curves of a Jominy Bar

If the experimentally determined oil-cooling curves shown in Fig. 2 are compared with the curves determined by Russell and Williamson[9] for points along the length of an end-quenched Jominy test specimen, marked differences between the shapes of the two sets of curves are clearly revealed. Whereas the oil-cooling curves have a distinct flat over the first part of the curve, there is no corresponding flat on the Jominy cooling curve. Consequently, if a Jominy cooling curve and an oil-cooling curve have equal ' half-temperature times,'[14] they cannot have similar rates of cooling in the transformation temperature range. The rate of cooling of the oil-quenched bar must always be greater, to offset the effect of its initially slower cooling. Relationships between Jominy distances and bar diameters derived using these ' half-temperature times ' as the criterion of equivalence of the cooling curves, are therefore open to criticism.

In Fig. 8, the cooling curves of oil-quenched bars (at temperatures below 700° C.) are compared with the corresponding portions of the cooling curves of those points in an end-quenched test specimen which take the same time to cool from 700° to 500° C. (these latter being obtained by interpolation of Russell and Williamson's data). The agreement between the two sets of cooling curves is extremely satisfactory, and is, in fact, distinctly better than that obtained using equal rate of cooling at 700° C. as the criterion of equivalence.

The Jominy positions which cool at the same rates as oil-quenched bars (based on equality of time to cool from 700° to 500° C.) are shown in Fig. 9.

CONCLUSIONS

The cooling of oil-quenched bars of up to at least 6 in. dia. can be closely simulated, over the temperature range in which transformation to non-martensitic structures is likely to occur, by air-cooling a bar of selected size. The sizes required to simulate the oil-cooling vary from 0·052 in. dia. for the centre of a 1-in. dia. bar to 0·890 in. dia. for the centre of a 6-in. dia. bar.

The experimentally determined cooling curves did not agree fully with curves calculated from the Tables published by Russell. It was found, however, that the differences between the cooling curves for the $r/b = 0$ and 0·8 positions of 2–6 in. dia. bars cooling freely in air were in accordance, over the temperature range 800–500° C., with the 'time-lag' equation used by Jackson and his collaborators.

Consideration of the results has shown also that for the cooling curves of bars quenched in oil and the cooling curves derived at points along the length of an end-quenched Jominy test specimen, an equivalence relationship based on a comparison of the curves at temperatures below about 700° C. is to be preferred to any method involving a comparison of the curves at higher temperatures. If the time to cool from 700° to 500° C. is used as the criterion of equivalence, then the degree of matching, over the temperature range within which transformations are likely to occur, is extremely close.

Acknowledgments

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Experimental Survey of Low-Load Hardness Testing Instruments

By A. R. G. Brown, M.Sc., L.I.M., and E. Ineson, B.Sc., A.I.M.

SYNOPSIS

A review of the literature is followed by a brief description of the available low-load hardness testers, and the method of operation used in this survey.

It appears that the absolute low-load hardness values obtained vary considerably, because of the large number of uncontrolled variables. The need for a standard method for preparing and testing specimens and for reporting results is shown.

Section I—REVIEW OF THE LITERATURE

The early history of hardness testing, in regard to scratch-testing instruments and the development of static hardness testers of the Brinell, Vickers and Rockwell types, has been adequately described. The relevant references are given by O'Neill.[1] Standard hardness testers of the static type give an average hardness figure for material under test[2] and

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in general do not give any indication of the hardness of the various constituents in complex structures, nor are they always suitable for measuring the hardness of thin sheets or coatings. This has led to the development of hardness testing with low loads, for accurate measurement over restricted areas *e.g.*, carbide particles in a tool steel. The term ' microhardness testing ' is usually applied to this technique but O'Neill[3] considered that a more accurate description was ' hardness testing by micro-indentation.' The latter, however, is cumbersome and the authors have used the phrase ' low-load hardness tests ' in this paper. The tests normally referred to as ' macro tests ' have been called ' standard tests.'

The earliest reference to a low-load hardness test appears in the National Physical Laboratory report for 1932.[4] An apparatus was described which permitted small loads to be applied to a 136° diamond pyramid indenter so that the hardness of metal coatings and thin specimens could be investigated.

Lips and Sack[5] suggested it would be convenient to measure the hardness of individual constituents to identify the structural elements. They designed a tester consisting of a Vickers diamond, attached to a small piston free to move in a cylinder. This was mounted on one side of a double nosepiece on a bench-type microscope. The specimen was brought into contact with the indenter, which was weighted by the piston bearing the diamond. The size of the impression was measured with an ocular micrometer. To increase the load the pressure of air in the cylinder above the piston was increased. This instrument apparently gave fairly reliable results.

Knoop and his associates,[6, 7] experimenting on the determination of the hardness of crystals and glasses, abandoned dynamic tests and developed a tester which produced indentations in the form of a pyramid based on a parallelogram with an included angle of approx. 16°. This was adopted because static tests using cone, ball or square base pyramid indenters caused excessive fracture of the material.

The Wilson Mechanical Instrument Division of the American Chain and Cable Co., Ltd., developed the Tukon tester, the design of which was approved by the National Bureau of Standards. With the early model of this tester there were large inertia effects ; the equipment was later modified to minimize these.[7–13]

About the same time Hanemann[14] produced a tester in which the indenter was mounted in the front lens of an objective ; the position of the indentation could thus be closely controlled. The instrument employed a new method of measuring the load, which involved the use, in the special objective, of a scale that could be viewed through the microscope eyepiece. In 1945 Hanemann[15] described a method of mounting the indenter in an oil-immersion type of objective, thus enabling small indentations to be measured more accurately.

Recently the number of testers available has increased considerably, the more important being those developed by Bergsman,[16] Girschig,[17] Cooke, Troughton and Simms,[18] Reichert,[19] Guest, Keen and Nettlefolds,[20] and the Safety in Mines Research Establishment.[21] Other testers have been described by Crawshaw,[22] Perryman,[23] Unckel,[24] Campbell, Henderson and Donleavy,[25] Eberbach,[26] Woxen,[27] Industrial Diamond Distributors,[28] and Lloyd and Norris.[29]

No effort has yet been made to compare the performances of the instruments, or to determine whether reproducible hardness values can be obtained, although Tate[30] reported that the Eberbach instrument (a spring-loaded tester with a Vickers diamond indenter) agreed reasonably well with the Tukon tester at loads above 200 g.

SOURCES OF ERROR IN HARDNESS DETERMINATIONS

Measurement of Indentation and Accuracy of Loading

The hardness of a material is defined as

$$\frac{\text{Load}}{\text{Area of contact of indentation}},$$

or

$$H_D = \frac{1854 \times P}{D^2}$$

for a 136° diamond pyramid indenter, where,

H_D = Vickers hardness
P = Load in grams
D = Diagonal length of indentation in microns.

It may be shown that the maximum error ΔH in H_D that can be caused by maximum errors of ΔD and ΔP in D and P respectively is given by

$$\frac{\Delta H}{H_D} = \frac{2\Delta D}{D} + \frac{\Delta P}{P}.$$

This equation shows that the major source of error is the measurement of the indentation.[31] It was originally thought that the long diagonals of the Knoop indentations could be more accurately measured than those of other indentations but, although the diagonal length at a given load is greater than that of a square indentation at the same load, it has been found difficult to determine the position of the ends of the long diagonal. Thibault and Nyquist[32] found that the optical equipment used affected the measurement of the Knoop indentation. Benford of Bausch and Lomb recommended a × 54, 1·00-N.A. fluorite oil-immersion objective and bright field illumination, as being the optimum equipment. The work was conducted on silicon carbide and aluminium oxide ; it was extended to steels by Tarasov and Thibault,[33] who assumed that the visibility error was zero for the objective with the highest N.A. (in this case a × 80 oil-immersion apochromatic objective of 1·40 N.A.) and showed that the error increased rapidly as the N.A. was reduced. Girschig[17] also considers the errors in measurement of the diagonal of impression and gives values of the minimum relative error for three different objectives.

The factor $\Delta P/P$ will vary with the instrument and some of the anomalous results obtained at very low loads may be partly due to inaccuracies in loading.

Surface Preparation of Materials Tested

The method of preparing the surface of the material for testing may also considerably affect the values obtained. Tate[30] in a reply to a discussion of his paper states that, as often occurs when a Tukon

tester with a Knoop indenter is used, the apparent hardness showed an increase at low loads; this effect was much less marked in electro-polished specimens. German workers[34] have reported a considerable superficial hardening due to mechanical polishing. Perryman[23] reports that electro-polished specimens return considerably lower hardness values than mechanically polished. A similar effect in steels has been found by workers at Stewarts and Lloyds,[35] and the previous survey carried out by the Mechanical Methods Sub-Committee of B.I.S.R.A., revealed the same tendencies.[36] Thus whenever there is any possibility of the surface of a specimen being work-hardened during mechanical polishing, the preparation should be carried out electrolytically.

Speed of Loading

The term 'speed of loading' is used to refer to the speed with which the indenter and the specimen approach each other immediately prior to the application of full load. Girschig[17] postulates a loading speed not exceeding 50 μ/sec. Bergsman states that the loading speed should be kept as constant as possible during different tests, and it should preferably be determined and stated with the hardness number. In his own work Bergsman[16c] used a loading speed of approx. 15 μ/sec. (1 mm./min.). Work at the G.K.N. Group Research Centre on the effects of loading speed has not yet been fully published.[31] In general, a constant, steady loading speed of the order of 10 to 20 μ/sec. is acceptable.

Effect of Orientation

The orientation of the indenter with respect to the crystallographic planes of the material being tested would be expected to exert some effect on the hardness values obtained because of the general anistropy of metals. O'Neill[37] showed that in single crystals of aluminium the dodecahedral (011) face has the greatest mean Brinell hardness and the cubic (001) face the lowest. However, the load required to give an indentation equal in diameter to the ball diameter (Ultimate Load) was found to be constant. Pfeil,[38] working on ferrite, concluded that the hardness of a single crystal of iron is the same for all crystallographic planes.

Low-load hardness testing has revealed appreciable variations of hardness with orientation. Regular changes in Knoop hardness with crystal orientation of silicon ferrite and zinc have been found by Daniels and Dunn.[39] Perryman[23] and Roth-Meyer[40] have shown that similar effects are obtained using a Vickers diamond indenter on super-purity aluminium, high purity copper, Tadanac lead, and zinc.

Method of Reporting Results

The results of low-load hardness tests must include a large number of details, *e.g.*, the load applied, details of orientation, 'Meyer' indices (*see* Appendix II), and speed of loading. Haneman[34] suggests that the hardness value should be reported for each of the standard diagonal lengths 5, 10, and 20 μ, for example,

$MH_5 = 208$ kg./sq. mm.
$MH_{10} = 175$ kg./sq. mm.
$MH_{20} = 130$ kg./sq. mm.

where MH is the low-load hardness and the suffices indicate the diagonal lengths.

Alternatively, Onitsch[41] reports low-load hardness for a single given diagonal length (10 μ), prefixed by the logarithmic exponent (*see* Appendix II) for example, $^{1\cdot76}MH_{10} = 175$ kg./sq. mm.

In view of the great amount of work now being undertaken in this field some standardization of the methods of reporting results is desirable.

Section II—INSTRUMENTS USED IN THE SURVEY

All the instruments investigated in this survey used a 136° diamond pyramid indenter, and will be considered according to their method of loading.

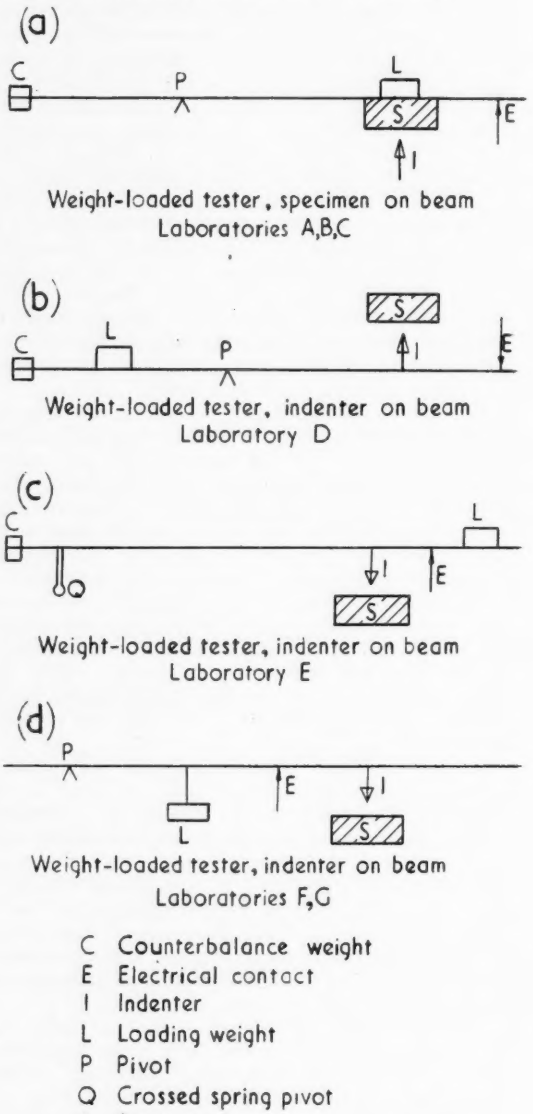

Fig. 1—Principle of operation of weight-loaded testers

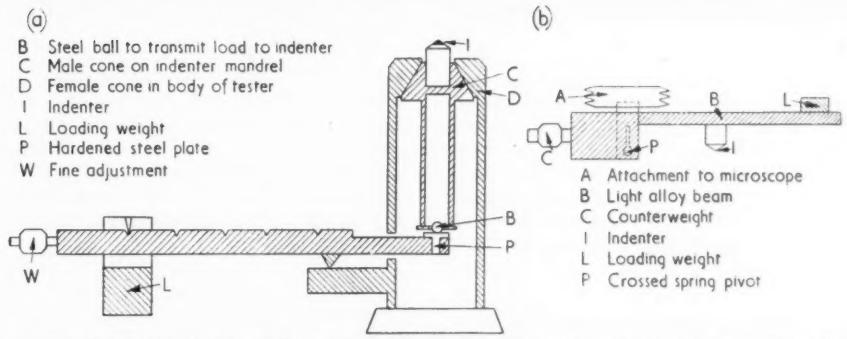

Fig. 2— Beam-loaded testers : (*a*) Stewarts and Lloyds tester ; (*b*) G.K.N. tester. (Reproduced by courtesy of Stewarts and Lloyds and G.K.N., respectively)

WEIGHT-LOADED TESTERS

Specimen on Beam—The specimen is attached to a beam and counter-balanced. A weight is then placed over the specimen, so that its centre of gravity is vertically above the point of the indenter. The beam system is lowered, or the indenter is raised, until the loaded beam is supported by the indenter which now presses into the surface of the specimen. The applied load is equal to the weight placed above the specimen. This method of operation is shown in Fig. 1*a*. Instruments in this group are the Bergsman,[16] and the Cooke, Troughton and Simms,[18] the main difference between them being that in the former the indenter replaces the microscope objective, whereas in the latter it is built into the front lens of the objective.

Indenter on Beam—The specimen is held rigidly, and the indenter supported on a balanced beam to which varying loads may be applied. There are three types of instrument :

(i) For use with an inverted microscope. This type, developed by Stewarts and Lloyds, is illustrated in Figs. 1*b* and 2*a*, the latter showing the general assembly of the instrument.

(ii) For use with a bench-type microscope. This type illustrated in Figs. 1*c* and 2*b* has been designed by Guest, Keen and Nettlefolds' research laboratories.[20] A crossed spring pivot and light alloy beam reduce inertia effects in the tester.

(iii) The Tukon tester.[11–13] A self-contained unit, this type was designed for use with a Knoop indenter, but can be used with the 136° diamond pyramid.

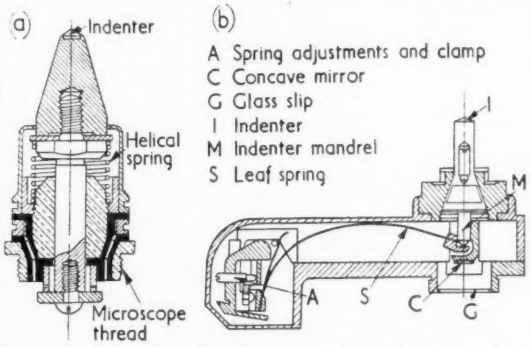

Fig. 3—Spring-loaded testers : (*a*) Safety in Mines Research Establishment tester. (Reproduced by courtesy of Journal of Scientific Instruments and S.M.R.E.) ; (*b*) Girschig Microsclerometer (Simplified). (Reproduced by courtesy of M. R. Girschig)

To improve the uncertain results at low loads of the earlier models, a torque arm and a solenoid device were introduced in the beam system. This complicated the loading cycle. The method of loading is shown in Fig. 1*d*.

Self-weighted Indenter—A further type of weight-loaded instrument is that developed by Perryman.[23] The construction is based on that of the helical-spring-loaded instrument illustrated in Fig. 3*a*. The applied load is the actual weight of the indenter and its supports.

SPRING-LOADED TESTERS

Helical-Spring Testers—This type, developed by Lloyd and Jeffrey,[21] is illustrated in Fig. 3*a*. Other instruments of this type are the modified Lips and Eberbach.

Leaf-Spring Testers—This type is represented by the Girschig[17] tester, shown in Fig. 3*b* ; it employs a unique system for the indication of full loading. (*See* Appendix I).

Disc-Spring Testers—The Zeiss-Hanemann instrument,[3, 14, 15] a self-contained unit in which the indenter is mounted in the front lens of the measuring objective, is of this type. The applied load is indicated by a scale viewed through the microscope eyepiece. When the indenter is loaded, the pressure of the specimen on the indenter causes a slight movement against the disc springs used for loading, and this is transmitted to the scale. A calibration curve of scale reading against load applied is readily obtained, as they are approximately proportional, and this makes control of the load possible.

Torsion-Bar Testers—The indenter and the measuring objective are separate, but the whole mechanism is carried on an accurately aligned slide, so that either may be brought on to the optical axis of the microscope at will. The load is determined from a scale reading in the microscope eyepiece. This type of tester is produced by Reichert of Vienna.[19]

The testers, both weight-loaded and spring-loaded, available in this country are given in Table I, and further details of the instruments used in the present survey in Table II. When assessing the advantages and disadvantages of the instruments the following features were considered :

The material to be tested should be held rigidly, with the surface to be tested normal to the axis of the indenter, by a device that is as universal as possible.

A sensitive method of loading the indenter, together

with some mechanism for checking the loading, should be incorporated.

Equipment should be provided to enable the indentation to be positioned with great accuracy.

Optical equipment should be provided to enable the small indentations to be accurately measured.

An indenter that is free to move in any direction as soon as the load is applied is called a ' free ' indenter ; most indenters can only move in a vertical direction.

A continental screw micrometer eyepiece, of slightly more complicated design than that normally employed in this country, permits the mean diagonal length of an indentation to be determined from one observation.[19]

Section III—EXPERIMENTAL WORK AND RESULTS

Material Used in the Survey

Eight specimens were prepared and the materials chosen, together with some critical comments, are given in Table III.

The 18/8 steel was dirty, but it was relatively easy to place the indentations away from the inclusions. However, the distribution of the inclusions beneath the indentations was unknown, and an indentation immediately above an inclusion may have given false hardness values. This also applies to specimens 6, 7, and 8 which had inclusions in fairly distinct bands with relatively inclusion-free material between the bands.

The specimens consisted of a single phase, or a very fine structure of two phases. Polishing was carefully controlled in order to produce a stress-free surface. The specimens were alternately electropolished using chrome-acetic acid reagent,[42] and etched until a clean surface was obtained. In some instances where pitting occurred, a light mechanical

Table I—THE MAIN TYPES OF LOW-LOAD HARDNESS TESTERS

Instrument and Type	Supply and Approx. Cost*	Advantages	Disadvantages
BERGSMANN[16] Beam loading Specimen on beam	Good £100	Simplicity of design Low cost Dead weight loading Great range of loads	Balancing of beam required for each specimen Specimen size limited Poor indication of loading
COOKE, TROUGHTON and SIMMS[18] Beam loading Specimen on beam	Fair £100	As above and Precision in placing indentation	As above and Diamond interferes with measurement Greater mass of moving parts of tester
STEWARTS and LLOYDS Beam loading Indenter on beam	—	Accurate loading " Free " indenter Accurate indication of loading Use of very low loads possible Infrequent calibration required	Instrument not available Lack of precision in placing indentation Exacting in use Skilled operator essential
G.K.N.[20] Beam loading Indenter on beam	Good £100	Accurate loading Accurate indication of full load Used on bench microscope Infrequent calibration required	Excessive load applied by racking too far Lack of precision in placing indentation may arise in use
TUKON[9–13] Beam loading Indenter on beam	Good $2000	Fully automatic Simple to use	High cost Complex control mechanism High speed of loading
PERRYMAN(B.N.F.)[22] Dead load, weight of indenter	—	Simplicity Accuracy of applied load Infrequent calibration required Used on bench microscope	Small loads only available Instrument not available
S.M.R.E.[21] Helical spring loaded	Good £35	Convenience in use Used on bench microscope Low cost	Frequent calibration essential Non standard loads obtained
GIRSCHIG[17]	Fair £130	" Free " indenter High Sensitivity Great range of loads Low inertia	Changing of load is a tedious operation Instrument trying to eyes in use Calibration required for each load change Calibration is exacting
ZEISS HANEMANN[14] Disc spring loaded	—	Convenience in use Ease of calibration Precision in placing indentation Scale indication of load	Diamond interferes with measurement Instrument not available Frequent calibration required
REICHERT[18] Torsion bar loaded	Good £150	Convenience in use Ease of calibration Precision in placing indentation Scale indication of load	Frequent calibration required

* Dash indicates not available

polish, followed by etching and electrolytic polishing, was undertaken. Specimen 3 was etched in nital. It was not practicable to obtain X-ray photograms or electron diffraction patterns to show the condition of the surface tested.

Testing Procedure

The testing procedure varied in different laboratories. (*See* Table II).

In laboratories *A*, *B*, *G*, *H*, *K*, *L*, *M*, *N*, and *O* two operators made independent series of tests, one of the authors (A.R.G.B.) being one operator in each case. In laboratories *E* and *F*, in which loading was fully automatic, one series of indentations was made, and these were measured by both operators. In laboratory *D* each operator made a series of indentations, which were measured by the normal operator, and checked periodically by A.R.G.B., who found that there was very close agreement. In laboratory *C* only one series of tests was made (by A.R.G.B.) because a second operator was not available.

The measuring systems were all calibrated by the same operator against a given stage micrometer. The correction factors for hardness values, obtained from the normal laboratory calibrations were mostly small, being of the order of $\times$ 0·998, and could not account for the large variations reported in an earlier survey.[36]

RESULTS

In Tables IV and V the mean hardness values obtained in the various laboratories are given.

These tables do not give an overall picture of the results, and it is difficult to compare values obtained in different laboratories, as in many cases corresponding loads are not employed. In Table VI, therefore, 'standard low-load hardness' values at a diagonal length of 10 μ are given. The values are obtained by plotting, on logarithmic scales, the load against the mean diagonal length of indentation, as shown in Fig. 4. This plot should give a straight line. The load required to produce an indentation with a mean diagonal length of 10 μ may be obtained by interpolation or extrapolation, and knowing this load the hardness may be calculated from the formula given in Section I. In addition, the logarithmic indices (*see* Appendix II) are given in this table.

For comparison the standard hardness values obtained with two Vickers hardness machines are given in Table VII.

It is difficult to present the results in a graphical manner, but the range of values obtained for each specimen on each instrument is illustrated in Fig. 5.

Table II

INSTRUMENTS USED IN THE EXPERIMENTS

Lab. Code No.	Laboratory	Tester	Indication of Full Load	Microscope	Duration of Application of Full Load, sec.	Measurement of Indentation	
						Method	Magnification
A	B.I.S.R.A. Labs. at Royal School of Mines	C.T.S.*	Micro-ammeter	C.T.S. *a*	15	Screw micrometer eyepiece	n.c.
B	United Steel Cos., C.R.D. Labs.	Bergsmann	Filament lamp	Reichert	15	Micrometer eyepiece	n.c.
C	Wm. Jessop and Sons Ltd.	Bergsmann	Filament lamp	C.T.S. *b*	15	Projection	1000
D	Stewarts and Lloyds, Corby	Stewarts and Lloyds	Micro-ammeter	Reichert	10	Projection	1000
E	G.K.N. Group Research	G.K.N.	Automatic loading	†Baker, bench type	20	Screw micrometer eyepiece	n.c.
F	A.E.R.E., Harwell	Tukon	Automatic loading	Measurement with Baker microscope	20	Screw micrometer eyepiece	n.c.
G	A.I.D., Harefield	Tukon	Automatic loading	Measurement with Bausch Lomb microscope	20	Screw micrometer eyepiece	n.c.
H	Safety in Mines Res. Est., Sheffield	Lloyd & Jeffrey (S.M.R.E.)	Micro-ammeter	Watson, bench type, for indentation ; C.T.S. *b* for measurement	15	Projection	2000
K	B.N.F.M.R.A.	Perryman	Filament lamp	†C.T.S., bench type, for indentation ; C.T.S. *b* for measurement	30	Projection	1500 1000
L	B.R., Lond. Mid. Region, Derby	Modified Lips	Filament lamp	C.T.S. *b*	15	Projection	1000
M	Mond Nickel Co.	Girschig	Optical	† Zeiss	20	Micrometer eyepiece	n.c.
N	B.I.S.R.A.	Reichert	Scale	Reichert	15	Screw micrometer eyepiece (Continental type)	n.c.
O	N.O.I.D., Bragg Lab.	Zeiss Hanemann	Scale	† Zeiss	15	Screw micrometer eyepiece (Continental type)	n.c.

a Vickers Projection Microscope with quadrant rack fine focusing
b Vickers Projection Microscope with helical thread for fine focusing
* C.T.S. = Cook, Troughton and Simms
† Microscope mounted on shock absorbers
n.c. = not calculated

Table III
MATERIALS USED IN THE EXPERIMENTS

Specimen	Material	Remarks
7	Oxygen-free, high-conductivity copper. Annealed	Prepared by B.N.F.M.R.A. Homogeneous.
2	Oxygen-free, high-conductivity copper. 50 % cold-worked	Prepared by B.N.F.M.R.A. Homogeneous, with few inclusions
3	Pure iron	Homogeneous, of fairly large grain size, with very few inclusions
4	Manganese austenitic steel. (13·8 % Mn). Water-toughened	Homogeneous, but surface hardness appears to vary considerably
5	Ni/Cr, austenitic steel (18/8). As rolled	Numerous inclusions
6	Low alloy case-carburized steel. Section of case tempered at 450 °C.	Numerous inclusions, chiefly in streaks. Very fine duplex structure of carbide and ferrite
7	As 6, but tempered at 300° C.	do.
8	As 6, but as-quenched	do.

Each ' block ' represents a range of values, and gives no indication of the variation with load, or the frequency of values obtained.

DISCUSSION OF RESULTS

The results indicate that considerable variations in hardness are found when a given specimen is tested on different instruments. The variations are apparently greater for the harder specimens (*see* Fig. 5) although

Table IV
HARDNESS VALUES AT LOADS BELOW 10 G.

Laboratory	Load, g.	Specimen Number				
		1	2	3	4	5
B	5	40·8	...	...	...	...
D	5	49	126	147	303	193
	2·5	50	140	173	...	...
	1	65	...	...	...	...
E	3	44·9	88	123	...	...
	1	40·8	...	...	...	...
N	5	54·2	114	141	...	...
	2·5	51·7	...	...	...	...

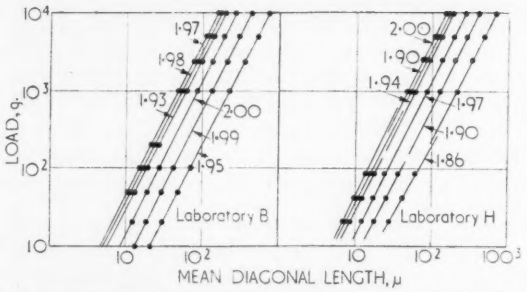

Fig. 4—Relationship between load and diagonal length. The logarithmic index *n* is given on the curve

the ratio of the range to the mean hardness is remarkably constant.

The results from laboratory *M* (Girschig tester) are in general low, while those from laboratory *D* (Stewarts and Lloyds tester) tend to be somewhat high. The Zeiss-Hanemann tester in laboratory *O* gives high results on the harder specimens.

Variation of Hardness with Load

It is impossible to state whether any general variation of hardness with load occurs. The logarithmic index *n* (*see* Appendix II) gives a measure of the variation for each individual laboratory. If $n = 2$ the hardness value is not affected by the applied load. If *n* is less than 2 the hardness appears to increase as the applied load is decreased, whereas if *n* is greater than 2 the hardness appears to decrease

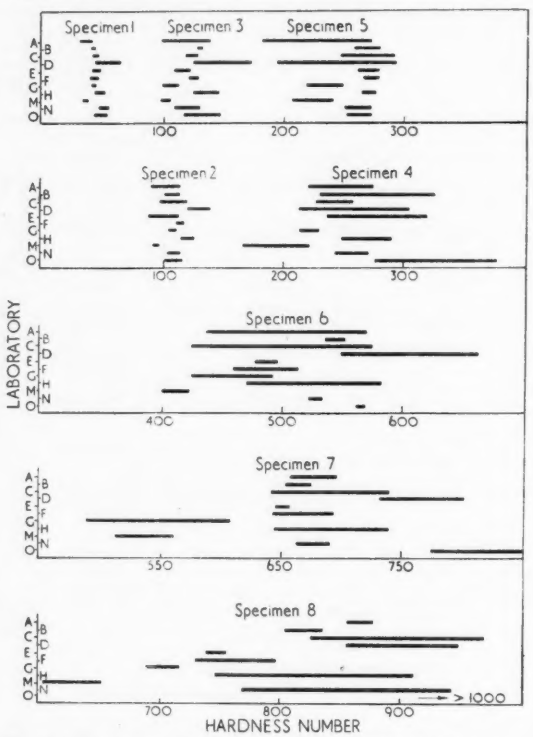

Fig. 5—Ranges of hardness values obtained for each specimen

Table V

HARDNESS VALUES AT LOADS EXCEEDING 10 G.

Laboratory	Load, g.	Specimen Number							
		1	2	3	4	5	6	7	8
A	100	*	115	139	252	272	570	696	877
	50	40·5	113	127	220	254	530	695	865
	20	34·5	92	119	220	215	437	659	†
	10	31	90	99	†	180	†	†	†
B	200	*	*	*	230	279	539	675	806
	100	40·2	111	129	297	265	535	659	803
	50	42·8	113	132	299	257	552	654	834
	20	43·8	117	130	325	257	†	†	†
	10	43·5	102	128	†	†	†	†	†
C	200	*	*	*	231	283	558	718	934
	100	44·0	121	118	233	286	575	739	824
	50	40·9	115	129	259	291	524	726	910
	20	44·5	113	121	243	254	425	643	969
	10	46·0	98	127	227	246	†	†	†
D	200	*	*	129	219	276	549	731	854
	120	*	126	—	—	—	565	740	898
	80	*	122	130	247	—	—	—	—
	50	42·5	125	125	238	292	556	742	947
	40	46·5	132	124	236	286	600	740	—
	20	46·5	124	126	280	281	607	800	919
	10	45·0	121	136	295	267	663	771	†
E	100	41·4	106	109	319	277	495	646	739
	30	43·6	114	114	236	269	479	658	756
	10	47·8	107	122	255	261	†	†	†
F	100	39·8	118	121	—	270	513	694	798
	50	45·1	113	124	—	265	479	644	729
	25	—	111	130	—	278	485	680	756
G	100	40·2	112	113	219	219	492	608	718
	50	42·8	110	113	213	229	458	553	696
	25	42·5	105	99	229	249	424	488	688
H	86	43·9	121	132	276	275	564	695	910
	42	43·9	115	124	247	271	470	644	745
	21	51·6	126	146	289	264	582	740	859
K	16·8	37·5	113	128	201	261	460	565	677
L	42	34·6	80	110	215	237	464	659	848
M	100	36·5	91·9	98	218	206	400	512	595
	30	33·4	95·9	106	167	227	423	561	649
	10	38·0	96·4	106	211	240	†	†	†
N	100	*	107	109	241	264	523	662	768
	50	46·4	104	129	243	250	523	683	828
	20	48·2	114	120	271	271	533	690	941
	10	49·9	112	131	†	260	†	†	†
O	100	*	110	117	275	256	568	774	1069
	50	43·5	117	123	321	272	562	850	1133
	20	53·3	116	136	376	252	†	†	†
	10	48·5	102	148	†	†	†	†	†

* = Load considered too high. Diagonal length of indentation unreasonably high
† = ,, ,, ,, low. ,, ,, ,, ,, too small for accurate measurement
Dash indicates no test.

Table VI—STANDARD LOW-LOAD HARDNESS VALUES AT DIAGONAL LENGTH OF 10μ
(Logarithmic indices are given in parenthesis)

Laboratory	Specimen Number						
	1	2	3	5	6	7	8
A	20·4 (2·46)	64·3 (2·52)	98 (2·23)	178 (2·5)	414 (2·31)	676 (2·02)	853 (1·97)
B	46·9 (1·95)	115 (1·99)	132 (2·01)	259 (2·00)	542 (1·98)	654 (1·98)	818 (1·97)
C	48·2 (1·95)	108 (2·03)	128 (1·95)	264 (2·02)	502 (2·15)	710 (2·06)	964 (1·92)
D	48·8 (1·90)	135 (1·93)	139 (1·91)	263 (2·10)	602 (1·92)	742 (1·95)	922 (1·94)
E	46·3 (1·93)	107 (2·00)	124 (1·88)	262 (2·00)	463 (2·12)	652 (2·07)	754 (2·00)
F	n.d.	97 (2·16)	152 (1·85)	292 (1·93)	472 (2·16)	659 (2·07)	766 (2·00)
G	45·1 (1·92)	109 (1·97)	89 (2·19)	262 (1·86)	461 (1·94)	576 (1·97)	n.d.
H	52·9 (1·86)	128 (1·90)	172 (1·76)	278 (1·97)	546 (1·94)	704 (1·90)	872 (2·00)
M	47·3 (1·84)	108 (1·88)	115 (1·84)	243 (1·83)	427 (1·93)	556 (1·90)	641 (1·92)
N	54·7 (1·90)	112 (1·93)	148 (1·80)	259 (2·00)	519 (1·96)	669 (1·94)	835 (1·76)
O	55·6 (1·84)	111 (2·00)	148 (1·78)	242 (2·07)	540 (1·88)	826 (1·82)	818 (1·96)

n.d. = not determined

as the applied load is decreased. Table VI shows that in many cases the logarithmic index approximates to 2, although there is no apparent regularity in the values reported. Laboratory *A* reported high logarithmic indices which were attributed to inertia effects in the instrument. Further tests at this laboratory, to investigate the cause of these high values, yielded indices which agreed more closely with those found elsewhere, although the values obtained by the observer common to all the laboratories were still consistently high. A detailed study of testing procedure has revealed no valid reason for this discrepancy, and it can only be concluded that it was caused by excessive friction in the bearings of the tester, which have been eliminated in operation over a period of some months.

Previous investigators have reported systematic increases in the values of the logarithmic index with cold work ; specimens 1 and 2 (annealed and cold-worked copper) show a slight increase for the cold-worked material but the increase is insignificant and certainly not of the order previously reported.

When the load is plotted against the diagonal length of indentation, the low-load test results for the

Table VII—RESULTS OF TESTS ON TWO STANDARD VICKERS HARDNESS MACHINES

Specimen	Mean Hardness at Load of :					
	1 kg.	2·5 kg.	5·0 kg.	10 kg.	30 kg.	100 kg.
1	41·1 38·7	38·7 36·2	38·2 36·8	37·3 37·2		
2	113 108	115 115	113 108	111 114	113 110	
3	118 116	102 106	106 105·5	101 96	91·2 91·8	
4	193 217	206 311	201 396	195 206	195 194	213 212
5	276 257	279 270	277 268	274 262	275 262	258 246
6	533 515	524 536	532 532	548 542	568 554	567 563
7	680 700	681 641	666 655	690 649	690 675	710 681
8	839 839	777 792	795 810	777 762	792 769	798 792

different laboratories fall into two categories according to whether they lie on the same line as the standard Vickers results or not (*see* Fig. 4). Laboratories *B*, *D*, *E*, and *N* show in general continuous straight lines from the highest to the lowest load used. The results from Laboratory *O* vary for different specimens and those for the remaining laboratories show a discontinuity.

At very low loads (below 10 g.) considerable variations of hardness are reported, although insufficient results have been obtained to be conclusive.

Differences in the Values by Two Observers

There are considerable differences in the results obtained by different observers, even where the same indentations are measured by the two observers (Laboratories *E* and *F*).

Statistical Analysis

The results have been analysed statistically for the presence of the following three properties :

(i) Effect of load on hardness
(ii) Differences in hardness values between machines
(iii) Differences between the two observers on each instrument,

and the analysis corroborates the statements made.

CONCLUSIONS

Large variations in hardness are reported when different testers are used to investigate the same specimens, and only consideration of the design of the instruments can give any indication of the probable correct value. However, there may be actual variations in the surface hardness of the specimens tested, and such variations are almost certainly responsible for the irregular results reported on the manganese austenitic steel.

It is difficult to estimate the relative merits of different indenting systems, because of the variations in laboratory conditions. It is, however, possible to say that beam-loaded testers, with the indenter on the beam, and torsion-bar-loaded testers appeared to be the most reliable and convenient in use.

From fundamental considerations of the existing methods of measuring indentations (*see* Appendix I), agreement must be poor when the diagonal lengths fall below approx. 12 μ. Referring to Fig. 6 it may be seen that under perfect conditions it is not advisable to use loads below 100, 50, and 25 g. for materials in the ranges 400–600, 200–400, and 100–200 V.P.N. respectively. As the apparent variations of hardness obtained with different testers greatly exceed those expected from theoretical considerations, other factors, such as the design of the instruments, the conditions under which they are operated, and the preparation of the specimens, must be operative. The results

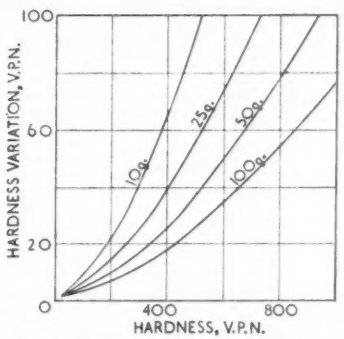

Fig. 6—Variation of hardness obtained on increasing diagonal length by $\frac{1}{2}$ μ

indicate that the minimum desirable loads are in practice higher than those suggested above. For materials with hardness greater than 200 V.P.N. (as measured on a standard Vickers hardness tester) a load of less than 100 g. appears to be undesirable. For materials with a hardness of 200 V.P.N. and less, large variations in the results occur at loads below approx. 50 g. When using weight-loaded testers that carry the specimen on the beam it is undesirable to use loads below 20 g. In brief, the maximum possible load permissible in any test should be used.

The wide variations in the reported hardness values obtained suggest that low-load hardness figures quoted in metallurgical literature have little absolute significance, particularly where no details of preparation of the specimens or the testing procedure are given. However, materials of differing hardness may be separated, if the same instrument is used, although the margin of error depends on the range of hardness. The following may be distinguished:

Range, V.P.N.	Difference definable, V.P.N.
0–100	20
100–400	50
above 400	100

The wide variations between different instruments make it impossible to report a definite effect of load on hardness, or to state any other general tendencies.

Further work is required before the general characteristics of low-load hardness testing can be enumerated. Standardization of methods of reporting results, testing procedure, and methods of specimen preparation are highly desirable. With reference to methods of reporting results, that of Onitsch[41] (*see* Section I) appears to be convenient, and permits different instruments to be compared irrespective of the actual loads employed. In addition, a number of problems, such as indenter characteristics, orientation of indenter, surface preparation of the specimens tested, and method of measuring indentations, require attention.

APPENDIX I—Operational Difficulties In The Testing Procedure

Inaccuracies in the Measurement of Indentations

The optical equipment in normal use, particularly the objective, places some limit on the accuracy with which indentations may be measured.

The least distance separable by a given objective is

$$x = \lambda/(2\mu \sin \alpha)$$

where $\mu \sin \alpha$ = N.A. of the objective and λ = wavelength of light used.

Table VIII

THEORETICAL ERRORS IN DIAGONAL-LENGTH MEASUREMENTS

(Using Green Light for Measurement)

N.A. of Objective	x, Å	Error in Knoop diagonal, μ	Δl, μ (Knoop)	Δl, μ (Vickers 136°)
0·45	5555	3·95	2·68	0·38
0·5	5000	3·56	2·29	0·32
0·6	4167	2·96	1·69	0·24
0·7	3751	2·54	1·27	0·18
0·8	3125	2·72	0·95	0·13
0·9	2777	1·98	0·71	0·10
1·0	2500	1·78	0·51	0·07
1·1	2273	1·62	0·35	0·05
1·2	2084	1·48	0·21	0·03
1·3	1923	1·37	0·10	0·01
1·4	1786	1·27	...	...

The diagonal length of a Vickers indentation will thus be reported short by a length x, so that for an 8-mm. objective of N.A. 0·45, using green light for which $\lambda = 5000$ Å,

$$x = 5556 \text{ Å},$$

i.e., the diagonal will appear 0·56 μ short. A further factor, namely the minimum distance resolvable by the human eye, is also involved, and in the case of the 8-mm. objective the normal magnification obtainable is such that the apparent error will be increased to approx. 0·75 μ. Thus, although with increasing N.A. of the measuring objective there will be an apparent increase in the diagonal of a given indentation, increase over the normal range of objectives will be approx. 0·5 μ under ideal conditions. It is doubtful whether such an increase can be consistently measured, although it would probably be indicated if a large number of readings were taken. For Knoop indentations with an included angle of approx. 16°, a similar calculation indicates that, over the normal range of objectives, there will be an apparent change of length of 2·5 μ, which should be detectable.

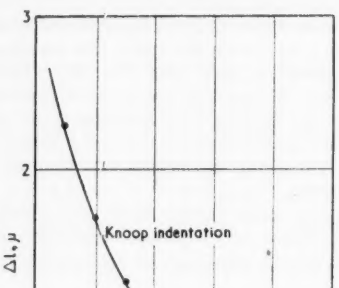

Fig. 7—Theoretical increase of diagonal length with increasing N.A. of measuring objective under perfect conditions using green Light ($\lambda = 5000$ Å)

Table IX

DIAGONAL LENGTHS OF VICKERS INDENTATIONS FOR OBJECTIVES OF DIFFERING N.A.

Method	Observer	Indentation No. 1				Indentation No. 2			
		N.A. 0·45	N.A. 0·65	N.A. 0·95	N.A. 1·30	N.A. 0·45	N.A. 0·65	N.A. 0·95	N.A. 1·30
Projection	1	16·0	15·8	16·25	17·0	8·0	7·25	8·4	8·75
	2	16·88	16·1	15·9	16·3	8·0	7·85	8·35	8·75
	3	16·15	15·9	16·9	16·9	8·45	8·1	8·85	8·75
	4	16·6	16·9	17·15	17·1	8·2	7·7	8·8	8·95
	5	15·75	16·2	17·05	17·0	8·2	8·1	8·9	8·4
Baker Screw Micrometer*	1	16·5	15·7	16·42	16·6	8·84	6·93	8·32	8·56
	2	17·9	16·5	16·21	16·6	9·3	8·36	8·32	8·36
	3	16·6	15·95	16·3	16·5	10·4	8·25	8·44	8·42
Baker Screw Micrometer* Green filter added	1	16·9		16·4	16·75	9·2		8·55	8·53
	2	16·75		16·35	16·49	9·05		8·71	8·57
	3	16·1		16·45	16·65	8·31		8·42	8·46
Baker Screw Micrometer* Tube length reduced	1	16·19		16·42	16·64	8·84		8·6	8·59
	2	14·65		16·42	16·65	8·84		8·6	8·74
	3	16·1		16·61	16·52	8·95		9·2	8·42

* Baker Screw Micrometer eyepiece used in conjunction with a ground glass diffuser and grey filter in each case

The results of a series of such calculations are given in Table VIII, in which the figure Δl, derived by the method of Tarasov and Thibault, is

Δl = (diagonal length with objective of N.A. 1·40) − (diagonal length obtained).

Figure 7 shows clearly the relatively great errors when measuring Knoop indentations.

The apparent variation of mean diagonal length of Vickers indentations with the N.A. of the objective used in measurement has been investigated experimentally :

(i) The images of two indentations were thrown on to a screen at a magnification of 1000, and measured with spring bow dividers by 5 observers. Each observer was unaware of the results obtained prior to his measurement, so that subconscious ' standardization ' was impossible. The Cooke, Troughton and Simms indenter objective (N.A. 0·65) was used with the measuring device supplied with the instrument for this work.

(ii) The same indentations were measured using the same objectives in conjunction with a Baker screw micrometer eyepiece, both with and without a green filter (*see* Table IX).

In all instances the magnifications were determined by one operator.

With the screw micrometer, the errors of measurement were of the same order as any possible increase in apparent diagonal length, *i.e.*, no systematic variation was observed. However, in the case of the projected images a slight tendency for the diagonal lengths to increase with the N.A. of the objective is recorded.

The apparent diagonal lengths of the indentations, as measured by the Cooke, Troughton and Simms indenting objective, were low; this is attributed to the reduction of the N.A. of this objective by the indenter in the front lens, and helps to account for the high hardness values reported on the Cooke, Troughton and Simms instrument in a preliminary series of tests.[36]

The effect on hardness values of variation of diagonal length is shown in Fig. 6. Assuming a given diagonal length, the error caused by reading a diagonal length 0·5 μ too high is plotted against hardness for various loads.

Observations during the survey have led to the conclusion that the errors involved in measuring a given diagonal length are approximately 0·5 μ, a figure in agreement with that advanced by Bergsmann, and Plaut and Thring.[43] Assuming an error of 0·5 μ it can thus be seen that with a load of 25 g. a variation of 40 is to be expected for a material with a hardness of 400.

Inertia Effects in the Various Instruments

The inertia of any moving part of the tester is of great importance, and has been investigated in some detail by Girschig,[17] who calculated that for the microsclerometer of his own design, with a load of 30 g., a surface hardness of 100 kg./sq. mm., and a velocity of loading of 1 mm./sec., the apparent hardness values would be 3·5% too low.

The greater the mass of the moving parts of the tester, and the greater the velocity of application of the load, the greater will be the inertia effects involved, and the lower will be the apparent hardness of any given surface. This appears to have been ignored in the design of many testers. The inertia effects in the beam-loading instruments (in which the specimen is carried on the beam and the mass of the moving parts will be quite large) will be considerable. A test was made with the instrument in Laboratory *A* in which the beam was balanced as in normal practice ; a hardness test was then conducted without any loading weight, *i.e.*, at zero load. An indentation was produced, even under very slow rates of loading, of a size comparable with that obtained at a load of 20 g. This was shown to be due to inertia effects by traversing the specimen while on zero load. No ' scratch ' was obtained, but merely a series of minute indentations due to vibration of the instrument during traverse.

Work on the effects of speed of loading in many laboratories in this country, has led to the conclusion that a loading speed of 10 μ/sec. is the maximum desirable.

Effect of Different Methods of Indicating Full Loading

Electrical—The application of full load is indicated by the breaking of a suitably placed contact (*see* Figs. 2 and 3). The original design, utilizing a 2·5- or 4·0-V. cell connected across the contacts and having a small filament lamp in the circuit, is open to criticism as considerable arcing may occur and this leads to wear of the contacts and partial extinction of the lamp. With testers having a ' free ' indenter it has been found that the arcing imparts a small kick to the indenter giving rise to enlarged indentations. The most satisfactory method of overcoming these difficulties is to connect a 2-V. cell in series with a half-megohm resistance across the contacts and measure the current with a micro-ammeter. Alternative systems employ miniature neon lamps, or high resistance relays.

Optical—This method employed by Girschig,[17] is sensitive, but somewhat trying when used continuously, due to the prolonged observation of a series of lines moving in and out of focus.

The Scale Method—This method, adopted in the Zeiss Hanemann instrument and the Reichert instrument, is convenient in use, and allows an infinite range of loads between the extreme values to be used. Calibration is easy, so that it is possible to standardize the scale before each series of tests.

APPENDIX II—A Note On The ' Meyer Analysis '

In 1908 Meyer[44] postulated an empirical relationship between applied load and diameter of indentation for the Brinell Static Ball Indentation Test given by

$$L = ad^n$$

where L = load, d = diameter of indentation, and a and n are constants.

By plotting log L against log d, the constants a and n may be evaluated. This process has become known as ' Meyer Analysis ' and the constant ' n ' as the ' Meyer Index.'

Investigation of the diamond pyramid indenter has shown that this relationship still holds and, because all the indentations of whatever size are geometrically similar, that $n = 2$ if the hardness of the material be independent of load.

Brown[45] has already shown that the term 'Meyer Index' is incorrectly applied to diamond indentations and this term should be changed to 'logarithmic index.'

In low-load hardness testing the logarithmic index is, in general, not equal to 2.

One investigator[46] has conducted experiments on the variations of the logarithmic index with cold work. It is reported that n varies regularly with the degree of cold work. There is some doubt as to the validity of the results obtained, and further work is desirable before any pronouncement can be made.

Interest in the values of the true Meyer Indices and their significance has recently revived, and a number of papers have been published on this subject.[47, 48]

Acknowledgments

The authors with to thank the Mechanical Methods Sub-Committee, of the British Iron and Steel Research Association, and all the co-operating laboratories, and investigators both in this country and abroad for their help and encouragement; also the manufacturers of testers who have allowed free comments on their products, and reproduction of drawings of the testers, and the Shandon Scientific Co., Ltd., who lent the Reichert instrument to B.I.S.R.A.

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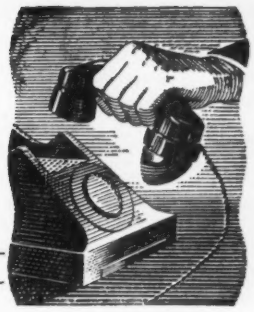
N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Symposium on the Corrosion of Buried Metals

CHANGE OF MEETING PLACE

The Symposium on the Corrosion of Buried Metals will now be held in the Lecture Theatre, The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2. The date and time (Wednesday, 12th December, 1951, at 10.0 A.M.), and the programme remain unchanged. This change is due to the large numbers wishing to attend the Symposium.

Verein Deutscher Eisenhüttenleute

(1) By agreement between the Councils, the arrangements for friendly collaboration between The Iron and Steel Institute and the Verein Deutscher Eisenhüttenleute, which were in force before the war, have been resumed.

(2) Application for membership of The Iron and Steel Institute from those of German nationality may now be made in the ordinary way. The standard rates of subscription, which include payment for the monthly *Journal*, are :

Ordinary Members	£4 4 0
Associate Members under the age of 25	£1 15 0

Forms of application for membership can be obtained from the Secretary of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

(3) The following special reduced rates of subscription are applicable to those who are members of the Verein Deutscher Eisenhüttenleute, or who are on the staffs of companies which are members of the Verein :

Ordinary Members	£3 13 6
Associate Members under the age of 25	£1 11 0

They, as well as former members who wish to apply for reinstatement, should apply through the Verein Deutscher Eisenhüttenleute, Breite Strasse 27, Düsseldorf, Germany. The following information is required : Full name and address, title and position held and, in the case of applicants for Associate Membership, date of birth.

(4) The Verein Deutscher Eisenhüttenleute is now also prepared to receive applications for reinstatement and membership. The annual subscription, which includes payment for " Stahl und Eisen " is 40 DM. Applications can be made either direct to the Verein or, in the case of Members of The Iron and Steel Institute, through the Secretary of the Institute. The following information is required : Full name and address, title and position held, date of birth.

(5) Dr. Ing. Dr.mont.e.h. Otto Petersen, who was elected an Honorary Member of The Iron and Steel Institute in 1937, has accepted an invitation from the Council to resume his Honorary Membership. Dr. Petersen was succeeded as Director of the Verein Deutscher Eisenhüttenleute by Mr. K. P. Harten in 1946.

NEWS OF MEMBERS

▶ Mr. S. ARABACIOĞLU has left the Cardiff Works of Messrs. Guest Keen Baldwins, Ltd., and after completing his military service in Turkey will take up an appointment at the Iron and Steel Works, Karabük, Turkey.

▶ Mr. J. C. ARROWSMITH. It is regretted that in the News Section of the September issue it was erroneously stated that Mr. Arrowsmith had recently joined the Pressed Steel Co., Ltd., Oxford. He has been in the Service of the Company for over 24 years.

▶ Dr. M. N. DASTUR has left H. A. Brassert and Company, Pittsburgh, to take up an appointment with the Washburn Wire Company, Rhode Island, U.S.A.

▶ Mr. R. M. ELLISON has left the British Iron and Steel Research Association to join the staff of Messrs. Pilkington Brothers, Ltd., St. Helens, Lancs.

▶ Mr. ARTHUR G. GILBERTSON, a Director of Messrs. Brown, Lenox and Co., Ltd., has been appointed Joint Manager of their Pontypridd Works.

▶ Mr. J. K. GILCHRIST has left the Research Department of Messrs. Babcock and Wilcox, Ltd., to take up an appointment as Lecturer in Metallurgy and Chemistry at Paisley Technical College, Glasgow.

▶ Mr. A. P. GREENOUGH has been awarded the degree of M.A. at the University of Cambridge. As reported last month, he is now at University College, Swansea.

▶ Mr. E. GREGORY has been awarded an E.C.A. Scholarship to study Production Technology and Management in the field of high-temperature materials. He is now at the University of Michigan, U.S.A.

▶ Mr. RAYMOND HAYNES has left the University of Sheffield to take up an appointment as Assistant Lecturer in Metallurgy at the University of Leeds.

▶ Mr. H. J. L. HERNE has left the Physics Department of the British Iron and Steel Research Association to take up an appointment with the Research Association of British Rubber Manufacturers, Croydon.

▶ Mr. J. E. HILLIARD has left Liverpool University to take up a temporary appointment as Research Associate in the Metallurgy Department of the Massachusetts Institute of Technology, U.S.A.

▶ Mr. D. W. HOPKINS has resigned from the position of Lecturer in the Metallurgy Department of the University College of Swansea, to take up an appointment as Works Manager of Western Metallurgical Industries Ltd., Neath.

▶ Mr. W. L. KERLIE, formerly Manager of Metallurgical Research at Messrs. Stewarts and Lloyds, Ltd., has left England to take up an appointment in the Research and Development Department of the United States Steel Company, Pittsburgh, U.S.A.

▶ Mr. P. L. J. LEDER has left Messrs. G. A. Harvey and Company (London) Ltd., to take up an appointment as Research and Development Manager of The Quasi-Arc Company Ltd., Bilston, Staffs.

▶ Monsieur F. PAUL LIST, Hon. British Consul for Luxembourg, has been awarded the M.B.E.

▶ Mr. M. LLEWELLYN has been awarded the degree of B.Sc. (Hons. Met.) of the University of Wales, and has taken up an appointment at the Ebbw Vale Works of Richard Thomas and Baldwins, Ltd.

▶ Mr. C. MCNAIR has resigned from his position as Manager of Foundry Steel Plants, Messrs. Hadfields, Ltd., to take up an appointment as Foundry Superintendent with Deloro Stellite, Ltd., Birmingham.

▶ Mr. J. F. MILLS, of the Engineering Department of the Metals Division of I.C.I., at Witton, has transferred to their Metals Division at Kidderminster, Worcs.

▶ Mr. J. E. OWSTON has left Messrs. Thos. Firth and John Brown, Ltd., to take up an appointment as Managing Director of Cravens Railway Carriage and Wagon Co., Ltd., Sheffield.

▶ Mr. A. R. PALMER has left the Royal School of Mines to take up an appointment at the Murongo Mines of the Colonial Development Corporation, Uganda.

▶ Mr. W. C. R. PENRY has been awarded the degree of B.Sc. (Hons. Met.) of the University of Wales. He is now at the Ebbw Vale Works of Richard Thomas and Baldwins, Ltd.

▶ Mr. C. W. RIDGE, of Scaw Metals Ltd., Johannesburg, is returning shortly to Bulawayo, Southern Rhodesia, to act as Consultant to a number of companies.

▶ Mr. A. D. SARKAR has left Messrs. Kumardhubi Engineering Works, Ltd., Bihar, India, to join the Coltness Iron Company, Ltd., Wishaw.

▶ Dr. T. E. SUESS has been appointed a Co-Director of Edward Hewson Partners Ltd., London.

▶ Mr. H. W. A. WARING, C.M.G., has resigned from his position as Secretary of Guest Keen Baldwins Iron and Steel Co., Ltd., and its subsidiaries, to take up an appointment as Director of the Power and Steel Division of the Secretariat of the United Nations Economic Commission for Europe, in Geneva.

▶ Mr. D. K. WORN has left the General Electric Company's Research Laboratories to take up an appointment in the Metallurgy Department of the Nelson Research Laboratories, The English Electric Co., Ltd., Stafford.

Obituary

Mr. J. D. ELLIS, formerly London Manager of the Birmingham Battery and Metal Co., Ltd., on 31st August, 1951.

Mr. EDWIN FORNANDER, formerly of Uddeholms A.B., Sweden, on 27th September, 1951.

Mr. T. F. MILLS, of Cheshire, on 20th February, 1951.

Mr. H. M. W. ROYCE, of Manchester, on 19th August, 1951.

Mr. F. WALKER, of the Chemical Research Laboratory of British Insulated Callender's Cables, Ltd., Liverpool, on 21st September, 1951.

CONTRIBUTORS TO THE JOURNAL

C. L. M. Cottrell, M.Sc.—Assistant Chief Metallurgist (Ferrous) to the British Welding Research Association. Mr. Cottrell was educated at Wellington School, Somerset, and at Birmingham University, where he graduated with the degree of B.Sc. (Metallurgy) in 1942. In 1950 he also obtained the degree of M.Sc. Mr. Cottrell was first employed in 1942 by the English Electric Co., Ltd., in their Research Department at Stafford, and later in their Welding Development Section at Preston, where he worked mainly on the metallurgical problems connected with welding. In 1946 he joined the staff of the B.W.R.A., and since that date has been leading a research team investigating the problem of hard-zone cracking in the metal arc-welding of low-alloy structural steels. Mr. Cottrell is the author of several papers on welding.

C. L. M. Cottrell

M. C. T. Bystram

M. C. T. Bystram, B.A.—Research Metallurgist, Murex Welding Processes, Ltd. Mr. Bystram was born in 1919 and was educated at Gymnasium-Lyceum in Rydzyna, Poland. He joined the Chemical Engineering Department of Warsaw-Polytechnika but his studies were interrupted by the war. He escaped from a prisoner-of-war camp in Germany and from a concentration camp in France to join the Polish Forces in Britain. At the end of the war he restarted his studies at Fitzwilliam House, University of Cambridge, and in 1948 he obtained an honours degree in metallurgy. He then took up his present appointment with Murex Welding Processes, Ltd.

IRON AND STEEL ENGINEERS GROUP

The **Sixteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 4th December, 1951.**

The Morning Session, from 10.30 A.M. to 12.45 P.M., will be devoted to the discussion of the paper by W. Udall on "Cooling Beds for Bar Mills" (November issue of the *Journal*, p. 257).

A Buffet Lunch will be available from 12.45 P.M. to 2.0 P.M. At the Afternoon Session a paper on American Rolling Mill Practice will be read by G. Foster (Dorman Long and Co., Ltd.). A précis of this paper will be circulated at the meeting, and the full paper will be published later in the *Journal*.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Spectrographic Analysis of Alloying Elements in Steel

Standardization proposals for the spectrographic analysis of alloying elements in steel were discussed at the 5th Chemists' Conference organized by the Association on 3rd and 4th October, 1951, at Leamington Spa. Dr. E. Gregory of Edgar Allen and Co., Ltd. was in the chair.

The problem of standardization is being tackled by a B.I.S.R.A. Sub-Committee, under the chairmanship of Mr. S. D. Steele of Babcock and Wilcox, Ltd. The proposals included the use of a quartz prism spectrograph; graphite counter-electrodes; an exciter with high-voltage and a low-capacity condenser with uncontrolled spark; calibration and standardization of photographic conditions by the use of specified iron spectral lines and line pairs of fixed intensity ratios for evaluation. Reproducibility in these conditions was expressed as a standard percentage deviation from the amount of a given element present in the steel.

The papers discussed at the conference included :

"*The Determination of Gases in Iron and Steel*," by G. E. Speight (United Steel Companies, Ltd.)

"*The Determination of Molybdenum in Low-Alloy Steels*," by S. W. Craven (I.C.I. Ltd., Alkali Division)

"*The Conflicting Behaviour of Molybdenum, Tungsten, and Vanadium in Absorptiometric Analysis*, by C. H. R. Gentry (Philips Electrical, Ltd.)

"*The Determination of Vanadium in Ferro-Vanadium*, by B. Bagshawe (Brown-Firth Research Laboratories)

"*The Determination of Nickel in Highly-Alloyed Steels*," by S. Harrison (Kayser, Ellison and Co., Ltd.)

In addition, Mr. W. Bullough (B.I.S.R.A.) gave a paper on "*The Disposal of Pickle Liquor with particular reference to Conservation of Sulphuric Acid*," in which he discussed batch pickling and continuous pickling of steel sheet. Mr. Bullough gave a description of a pilot plant for testing an autoxidation process, developed by B.I.S.R.A. for producing dilute acid (possibly up to 40%). The process is being tested in South Wales at the rate of one ton of dilute acid per day. If successful, full-scale plants will probably operate at ten or twenty times this rate.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

To commemorate the Festival year, the Council are offering prizes to members of the Society, not over 30 years of age, for the two best papers submitted with one of the following titles : "Clean Steel !" ; "Fighting Corrosion !" ; "Gas or Oil in Metallurgy ?"

INSTITUTION OF METALLURGISTS

Examination Results

The following candidates have been successful in the Institution's examinations held in 1951 :

Associateship—K. G. Blackmore (Liverpool) ; P. Bradley (Aylesbury) ; D. Cemm (Lewisham) ; J. Cowie (Kilbirnie) ; D. Davies (Birmingham) ; J. Donaldson (Glasgow) ; C. Ford (Glasgow) ; J. F. Giblin (St. Helens) ; C. C. Hanson (Walsall) ; J. Hines (Nuneaton) ; S. R. A. Langford (Brockley) ; R. M. Loach (Bilston) ; R. C. Lloyd (Birmingham) ; R. Mills (Streatham Common) ; M. W. Randall (Coventry) ; N. F. Sheppard (Hornsey) ; E. Ward (Doncaster) ; T. Williams (Ruddington).

Licentiateship—R. G. Bretherton (Croston) ; N. T. Burgess (Merstham) ; J. W. Campbell (London) ; W. H. Casling (Heston) ; J. D. Chadwick (Clapham Common) ; D. J. Fricker (Slough) ; P. Gregory (Farnborough) ; E. G. Hall (Slough) ; J. R. Hawley (Leicester) ; A. Milligan (Rosyth) ; R. K. Mitra (India) ; C. Morris (Stoke Gifford) ; R. J. Page (Uxbridge) ; E. C. Sykes (Palmers Green) ; P. C. Thornton (Birmingham) ; W. R. Utteridge (Coventry).

The following candidates satisfied the Examiners in the Associateship Examination but their election is deferred until they have been able to comply with the regulations in respect of age and/or experience :

R. J. Beishon (Wembley) ; D. Bindley (Allesley) ; H. Brunner (London) ; A. R. Daniel (Morden) ; P. H. Meade (Wirral) ; R. C. Perriton (Worcester Park) ; R. W. Shapton (Danygraig).

MEMOIR

Fred Clements, who died on 19th September, 1951, was born in 1882. He became apprenticed to Messrs. Markham, Chesterfield, and in 1902 won an Exhibition which enabled him to study engineering at Sheffield University. He joined the Park Gate Iron and Steel Co., Ltd., in 1903, and was appointed General Manager in 1923. He was elected to the Board in 1935, and in 1937 he became Managing Director of the Company. He was elected Chairman in 1940, and although he resigned from the Board of Directors in 1946, he continued to serve the Company as a Technical Consultant until his death.

Mr. Clements, who was a Whitworth Exhibitioner, was a member of the Institution of Civil Engineers, the Institution of Electrical Engineers, and the Institution of Mechanical Engineers, and was Chairman of the Yorkshire Branch of that Institution during 1923. He was also a member of the Association of Iron and Steel Engineers in the U.S.A., a Fellow of the Royal Astronomical Society, and a member of the British Astronomical Association, and was a Freeman of the Cutlers Company. His well-known book "Blast-Furnace Practice" was published in 1929.

Mr. Clements was elected a Member of The Iron and Steel Institute in 1920 ; he became Vice-President in 1940, and an Honorary Vice-President in 1946. In 1936 he was awarded the Bessemer Gold Medal of the Institute for his services to the iron and steel industry.

NEWS OF SCIENCE AND INDUSTRY

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee has pleasure in announcing the following awards for 1951 :

Mr. J. PRESTON (British Non-Ferrous Metals Research Association) to study, in Great Britain, the United States of America, and Canada, specialized methods of production and fabrication of metals with particular reference to powder-metallurgical techniques.

Mr. P. E. WHITE (Messrs. J. B. and S. Lees, Ltd.) to study the metallurgy and detailed production technique of high-quality strip steels in the United Kingdom, Scandinavia, United States of America, and Canada, with particular reference to hardened and tempered steel strip, stainless steels, and silicon steels.

United Steel Companies, Ltd.

On 26th September, 1951, No. 10 blast-furnace was blown-in at the Appleby-Frodingham Steel Company after a reline, which is believed to be the quickest ever done in this country. The blowing-in took place 32½ days after the blast was taken off. During this time a complete reline was carried out, the hearth being increased from 22½ to 25 ft. in diameter. Auxiliary equipment was overhauled and extensive modifications were made to adjacent railroads.

Richard Thomas and Baldwins, Ltd.

A new blast-furnace with an average weekly increase in output of 500 tons, was blown-in at Redbourn Works, Scunthorpe, on 2nd October, 1951. The new furnace replaces two old-type furnaces.

United States Study Tour

Eighty specialists, divided into three expert missions, visited the United States in October under the O.E.E.C. technical assistance scheme, to study respectively, galvanizing techniques, non-ferrous heavy metal fabrication, and smelting and refining of non-ferrous metals.

Four Members of The Iron and Steel Institute were members of the mission on galvanizing techniques : R. W. Bailey (Zinc Development Association), Secretary to the Mission, B. Ryan (Rylands Brothers, Ltd.), A. Clift (Stewarts and Lloyds, Ltd.), C. G. Davies (Richard Thomas and Baldwins, Ltd.). Mr. C. F. Davey (Member), (T. Boulton and Sons, Ltd.), was a member of the mission on non-ferrous heavy metal fabrication.

Company Changes

The Steel Corporation have announced the reconstitution of the Boards of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., and Messrs. Guest, Keen and Nettlefolds (S. Wales) Ltd.

Retiring from the Board of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., are Mr. J. H. JOLLY (Chairman) and part-time Directors The Hon. R. G. LYTTELTON and Mr. K. S. Peacock. The full-time Executive Directors will be: Mr. C. R. WHEELER and Mr. T. JOLLY (Managing Directors), and Mr. E. H. LEVER, Mr. H. F. Spencer, and Mr. J. S. HOLLINGS, who remain on the Board. Retiring from the Board of Messrs. Guest, Keen and Nettlefolds (S. Wales) Ltd., are Mr. K. S. Peacock (Chairman), Mr. J. H. JOLLY, Mr. A. F. Gadsby, Mr. M. H. Tollit, Mr. W. W. Fea, and Mr. W. A. Nicol (Secretary). The full-time Executive Directors will be Mr. N. R. BROOKE (General Manager), Mr. G. A. PHIPPS (Works Manager), and Mr. E. Brown (Commercial Manager).

In the reorganization, the management of these two Companies will become closely associated with that of Messrs. Richard Thomas and Baldwins, Ltd.

DIARY

4th Dec.—IRON AND STEEL ENGINEERS GROUP—Sixteenth Meeting—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

4th Dec.—INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—"*The Manufacture of Steel Chain and Slings*," by W. G. Biggart—39 Elmbank Crescent, Glasgow, 6.30 P.M.

4th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*The Applications of Cupferron and 8-Hydroxyquinoline to Metallurgical Analysis*," by E. W. Harpham and G. Robinson—Grand Hotel, Sheffield, 7 P.M.

5th Dec.—INSTITUTE OF WELDING—Symposium on Recent Developments in Notch-Bar Testing of Materials and their Relation to Welded Construction—Institution of Civil Engineers, Great George Street, London, S.W.1, 10 A.M.

5th Dec.—INSTITUTION OF ELECTRICAL ENGINEERS—"*Modern Development in Electric Welding*," by H. G. Taylor—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough 6.30 P.M.

6th Dec.—INSTITUTE OF WELDING (South London Branch)—"*Inside the Welding Arc*," by L. H. Orton—Institute of Marine Engineers, 85 The Minories, E.C.3, 6.30 P.M.

8th Dec.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Powder Metallurgy*," by J. C. Chaston—Central Library, Swansea, 6.30 P.M.

10th Dec.—INSTITUTE OF METALS (Scottish Local Section)—Symposium on Materials Testing—Institution of Engineers and Shipbuilders in Scotland. 39 Elmbank Crescent, Glasgow, C.2, 6.30 P.M.

10th–15th Dec.—SPANISH IRON AND STEEL INSTITUTE—Conference in Madrid.

11th Dec.—INSTITUTE OF MARINE ENGINEERS—"*Ductile Cast Iron*," by M. M. Hallett—85 The Minories, London, E.C.3, 5.30 P.M.

11th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Resistance of Gas Turbine Alloys to Scaling and Vanadium Attack*," by H. C. Child and "*The Evaluation of Residual Stresses in Metals by X-rays*," by L. G. Finch—Grand Hotel, Sheffield, 7 P.M.

12th Dec.—IRON AND STEEL INSTITUTE—Symposium on the Corrosion of Buried Metals—Lecture Theatre, Institution of Electrical Engineers, Savoy Place, W.C.2, 10.0 A.M.

12th Dec.—NORTH WALES METALLURGICAL SOCIETY—"*Research in Deep Drawing*," by H. W. Swift—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

14th Dec.—LIVERPOOL METALLURGICAL SOCIETY (Joint Meeting with North Wales Metallurgical Society)—"*Metallic Coatings*," by D. L. Phillips—Electricity Service Centre, Whitechapel, Liverpool, 7 P.M.

14th Dec.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Factors Determining the Teeming Temperature of Open-Hearth Steel*," by Mrs. A. Donald and D. Hadfield—39 Elmbank Crescent, Glasgow, 6.45 P.M.

17th Dec.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*A Rational Theory of the Hardening of Steel*," by A. H. Marks—The University Building, St. George's Square, Sheffield, 7.30 P.M.

18th Dec.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—"*Iron and Steel Developments at Port Talbot*," by W. F. Cartwright—Wortley Hotel, Scunthorpe, 7.30 P.M.

3rd Jan.—INSTITUTE OF METALS (London Local Section)—"*Research on the Working of Metals*," by W. C. F. Hessenberg—4 Grosvenor Gardens, London, S.W.1, 7.0 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the November, 1951, issue of the *Journal*, p. 280).

TRANSLATIONS AVAILABLE

No. 426 (German). H. POHL: "Investigations into Increasing the Efficiency of Band Sintering Plants." (*Stahl und Eisen*, 1951, vol. 71, June 7, pp. 597–605; June 21, pp. 664–669).

No. 427 (French). P. ROCQUET and M. OLETTE: "Growth of Cast Irons. Application to the Study of the Growth of Ingot-Mould Irons." (*Fonderie*, 1951, vol. 67, July, pp. 2565–2577).

No. 428 (German). W. LUEG: "Methods and Apparatus for Measuring the Profiles of Drawing Dies." (*Stahl und Eisen*, 1950, vol. 70, July 20, pp. 633–640). (Translation made available through the courtesy of The British Iron and Steel Research Association. Members of that Association may obtain copies free of charge on application to B.I.S.R.A.).

No. 429 (German). W. LUEG: "Improvement of the Quality of Drawing Dies by Supervision of the Die Profile Using Modern Measuring Methods." (*Stahl und Eisen*, 1951, vol. 71, Feb. 15, pp. 157–170). (Translation made available through the courtesy of The British Iron and Steel Research Association. Members of that Association may obtain copies free of charge on application to B.I.S.R.A.).

TRANSLATION IN COURSE OF PREPARATION

The purpose of this announcement is merely to give advance notice of the intention to prepare translations, and orders should not be sent in until a further announcement appears under "Translations Available."

(Hungarian). A. B. CHELYUSTKIN and B. A. LEVITANSKIY: "Automatic Control of Various Operations in the Iron and Steel Industry." (*Bányászati és Kohászati Lapok*, 1950, vol. 5, Dec., pp. 700–704).

(German). E. PIWOWARSKY: "Status, Development and Future of Nodular Grey Cast Iron." (*Neue Giesserei, Technisch-Wissenschaftliche Beihefte*, 1950, No. 4, Dec., pp. 175–180).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Raw Materials for Iron and Steel. F. H. Henson. (Discovery, 1951, vol. 12, Sept., pp. 279–287). The geological origin and location of iron ores in England are surveyed. Methods of working and smelting are outlined.—T. E. D.

A Review of World Coal and Iron Ore Resources and their Utilization for Manufacture of Steel. W. C. Rueckel. (Eastern States and Chicago District Blast Furnace and Coke Oven Associations: Blast Furnace and Steel Plant, 1951, vol. 39, Feb., pp. 195–199; Mar., pp. 327–332; Apr., pp. 426–438; May, pp. 540–548). The U.S.A. and Canada contain 58% of the estimated world reserves of bituminous coal. Europe contains 18%, whilst Asia has 19% of which only 2% is in Russia. The total reserve behind the Iron Curtain is about 21%. The 17,500,000,000 tons of iron available in the world would last 156 years if used at the record rate of 112,000,000 tons as in 1943. The U.S.A. has reserves of 5,500,000,000 tons which would last 55–60 years at the present consumption rate whilst Russia has 5,400,000,000 tons. The major iron ore producing countries are United States, France, Russia, Germany, and Great Britain and their respective maximum productions are 105,000,000 tons, 50,000,000 tons, 29,000,000 tons, 17,000,000 tons, and 20,000,000 tons. In 1944 the United States produced 71,000,000 tons of coke and 81,500,000 tons of steel. About 80% of this steel was produced in the Northeastern (Pittsburgh) district where blast-furnace practice is based on the high grade Mesabi ore, which is becoming rapidly depleted and may be replaced by cheaply transported ore from Venezuela and Labrador. Germany has a maximum production of 25,500,000 tons of steel ingots, 24,500,000 tons of pig iron, and 52,000,000 tons of coke. Great Britain can produce 16,000,000 tons of steel ingots, 9,000,000 tons of pig iron, and 29,000,000 tons of coke as against the French production of 10,000,000 tons of steel ingots. In Russia coke and steel production has increased from 2,000,000 tons in 1925 to 20,000,000 tons in 1938. Japan increased her steel production from 1,500,000 tons in 1925 to 8,000,000 tons in 1940. Manchuria and Korea supplied 3,000,000 tons of pig iron and 9,000,000 tons of iron ore to Japan in 1943. Sweden, Italy and Czechoslovakia all produce annually about 2,000,000 tons of steel. Brazil's reserves of high grade ore are estimated to exceed 4,000,000,000 tons—E. J. B

An Appraisal of the Iron-Ore Resources of the World—An American Estimate. J. W. Gruner. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 4–17). The iron-ore reserves of the world are discussed with particular reference to their availability and use within the next 30 or 40 years. Ignoring potential ore reserves (those which are difficult to mine or of extremely low grade) and counting only the actual ones, it is concluded that only the U.S.A. and the U.S.S.R. have sufficient iron ore and coal to develop and expand their steel industries. The quantity of ores which will be used in the U.S.A. in 1960 is predicted—T. E. D.

ORES—MINING AND TREATMENT

Testing of Sinter. E. G. Hill and R. E. Powers. (American Iron and Steel Institute, May 23–24, 1951, Preprint). To enable sinter plants to establish quality control tests for sinter, the authors describe methods tried on a laboratory scale which appear promising for control work. The properties considered include size, chemical analysis, hot and cold strength, porosity, reducibility, magnetic analysis, and microstructure.—G. F.

Recent and Prospective Sinter Plant Improvements. A. A. Nilsen. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author discusses recent developments and possible future improvements in sinter plant operation. The aspects considered include: (1) Cooling, breaking, and screening of the sinter; (2) handling and storage of the materials; (3) collection of the flue dust; and (4) mechanical improvements in the machines.—G. F.

Improving Current Practice in Blast Furnace Sintering. R. E. Powers. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author discusses possible means of improving blast-furnace sinter and sintering practice. Past and present experience in the use of sinter is first surveyed, followed by a consideration of the properties which are desirable in sintered ore. A critical examination is then presented of sintering practices at several works. It is concluded that improvements can be made in both the level and uniformity of the properties of sinter, and also in the plants and operating practices, which would give closer control, greater efficiency, and higher production rates. Finally, recommendations for plant design and operation, research and development, and blast-furnace testing, are listed.—G. F.

Present Methods of Grading and Grouping Iron Ores. N. H. Thomas. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 187–194). The mines, in order to give a chemical and tonnage guarantee, use detailed exploration records and previous mining experience to arrive at

a production and average analysis that can be used throughout the seven months shipping season. In addition, for both open pits and underground mines, the stock piles accumulated during the winter indicate what can be expected in the next seven months. Sampling methods have proved satisfactory, analyses of ore going into stock and ore shipped out of stock being compared. Methods of regulating the loading from shafts, stock piles and pits, and systems in use at the docks, in particular the block system, are outlined. A typical steamer load is also examined. Finally, the desirability of 'grouping' ores of similar analysis is discussed.—T. E. D.

New Method of Separation by Dense Media. H. Barking. (Revue de l'Industrie Minerale, 1951, vol. 31, Mar., pp. 548–555). A description of a dense media plant at Walsam mine is given with details of density control, purification and recovery of magnetite, power consumption, etc.—A. G.

Pelletizing of Iron-Bearing Fines by Extrusion. P. E. Cavanagh. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 54–80). Agglomeration of ore fines is surveyed, and the work of the Ontario Research Foundation on the subject is outlined. Required properties of pellets are suggested, and the effect of ore-swelling characteristics is mentioned. The behaviour of pellets during heating and reduction was determined by a standardized testing method, in which they were heated in saggers in a coke-breeze/limestone mix at 300° F./hr. to 2000° F. Many results are given. A brief account of the vacuum extrusion process of pelletizing is given, and the effect of binders is examined. Pellet performance was assessed by a 6-ft. drop test and a tumbling test at 2000° F. in a rotary kiln. Standard reducibility tests at 800° C. and 900° C. in hydrogen and in CO were made on ores, sinters, pellets, and briquettes. An estimate is given of capital and production costs for a 50 ton/hr. extrusion plant.—T. E. D.

Fundamental Factors Influencing the Strength of Green and Burned Pellets Made from Fine Magnetite Ore Concentrates. M. Tigerschiöld and P. A. Ilmoni. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 18–53). This is an English version of a paper which appeared in Jernkontorets Annaler, 1950, vol. 134, No. 4, pp. 135–170 (*see* Journ. I. and S.I., 1951, vol. 167, Mar., p. 328).

Principles and Operation of the Pan Sintering Process with Particular Reference to the Sintering of Fine Ore. H. Huisken. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 701–707). Sinter for efficient working of blast-furnaces should have a high strength, minimum amount of slagging, high porosity, and a high degree of oxidation. The pan sintering plants developed by the Gutehoffnungshütte for the treatment of fine ores fulfils all conditions for the production of a high-grade sinter. Their construction and operation are described. They are claimed to be suitable for the largest outputs and, because of readily adjustable suction area, can be matched to all types of ores.—J. P.

Reducing the Costs of Sintering Iron Ores. K. Meyer. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 727–728). The results of trials have shown that double layer sintering, with reduced coke in the lower layer, can lower costs appreciably and yet produce a satisfactory sinter, free from slagging.—J. P.

New Achievements in the Wet Preparation of Acid Ores. A. Goltz. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Aug. 1, pp. 717–718). Owing to plant dismantling at the Salzgitter-Watenstedt works the wet method of ore preparation has superseded others. Some details of the flotation method shortly to be used are given.—J. G. W.

Investigations into the Output of Belt Sintering Plants. H. Pohl. (Stahl und Eisen, 1951, vol. 71, June 7, pp. 597–605; June 21, pp. 664–669: Iron and Steel Institute, 1951, Translation Series No. 426). Trials have been carried out on an experimental ore sintering plant. The preparation and pretreatment of raw materials and of the sinter mixture and their effects on air permeability, are described. Trials with varying types, amounts, and particle sizes of solid fuels have indicated the most efficient and economic way to use fuel. Increasing amounts of moisture in a basic sinter mixture first decrease sinter times to a minimum, at 14·5% moisture, and then increase it again. Increasing wind pressure also reduces sinter times and thus increases output. The effect of increasing charge thickness is to decrease fuel requirements and to increase sinter times, though the increase in time per unit of thickness is small. It was also shown that increasing mixing time increases air permeability. Under otherwise similar conditions, reduction of ore size increases sintering times and using coarse ore decreases it. Increasing the lime content of the charge improves the air permeability and reduces sinter times but does not appreciably raise output and actually reduces the sinter quality. The best type and amount of lime or dolomite splinter to use as a cover for the sinter belt has been determined. The effect and subsequent fate of adventitious impurities such as sulphur, arsenic, sodium, potassium, lead, and zinc are discussed.—J. P.

Beneficiation of Adirondack Magnetite. W. R. Webb and R. G. Fleck. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 220–236). Of U.S. output of iron ore 2·85% was from the Lake Superior region in 1948, and the mined ore in the four Adirondack operations was 7,230,000 tons, representing 2,868,000 tons of magnetic concentrates, of which 70% were sintered at the mines; 250,000 tons of ilmenite were also produced. Open-cast working by blasting is mainly used, and gyratory crushers are employed before wet-belt magnetic separation. Further crushing by rod and ball mills, and final separation yields a 63·75% Fe product. Pilot-plant trials on a spiral concentrator for non-magnetic materials have been successful. Sintering is carried out in Dwight-Lloyd continuous and Greenawalt batch processes using anthracite for fuel.—T. E. D.

Swedish Sintering Practice—The Holmberg System. A. W. Robinson. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 246–267). In 1939, the proportion of sinter in blast-furnace burdens in Sweden reached 80%. Six Holmberg plants are in operation, with capacities from 110 to 485 tons/day. Sintering is done in a series of pans, 11 ft. 6 in. square, with robust Cr–V steel grate bars, which have a life of 5 to 6 years. A flow sheet and details of equipment are given. Operating costs, were $0·53/ton. Advantages include low fuel consumption and absence of moving parts in the sintering zones. The technical considerations discussed include the rôle of water in the charge, the size of fuel particles, mixing, and combustion. A mechanism of sintering is postulated, and the relation between quality and degree of oxidation is mentioned.—T. E. D.

Beneficiation of Jacutinga Ore (Brazil). A. H. da Silveira Feijo. (Revista de Química Industrial, 1951, vol. 20, Feb., pp. 12–15). [In Portuguese]. Most of the rich iron ores in central Minas Geraes contain much fines. This article discusses methods of agglomerating Jacutinga ore with alumina, cement, and blast-furnace slag, as well as briquetting pure Jacutinga. Jacutinga samples contained SiO_2 0·86, Fe_2O_3 98·39, MnO 0·23, P 0·012, Al_2O_3 0·77, and S 0·012%.—R. S.

FUEL—PREPARATION, PROPERTIES, AND USES

The Combustion of Carbon. W. van Loon. (Chemisch Weekblad, 1951, vol. 47, Apr., 21, pp. 233–239). [In Dutch]. The author discusses the mechanism and kinetics of combustion and gasification reactions of carbon. The calculations show, for a given gas velocity, the relationship between the specific reaction velocity and the reaction temperature of the carbon. If the gas velocity is low and the furnace hearth not well insulated, a considerable quantity of heat can be lost from the surface of the carbon by radiation as well as by convection. Thus, the furnace hearth temperature can be considerably lower than the maximum temperature of the reaction between the carbon and the gas component.—R. S.

Industrial Stacks and Their Uses. W. Trinks. (Industrial Heating, 1951, vol. 18, Mar., pp. 442–446). The problem of the removal of waste gases from industrial furnaces is discussed in general terms. The problem of removal of gases containing solid particles is considered in more detail.—J. A. L.

Investigation of Turbulent Flames. B. Karlovitz, D. W. Denniston, jun., and F. E. Wells. (Journal of Chemical Physics, 1951, vol. 19, May, pp. 541–547). A new theory of turbulent burning velocity is presented, which, when compared with experimental results leads to the recognition that the turbulent flame itself generates additional turbulence. A mechanism for this generation is formulated. Further experimental data supporting the theory are given.—J. A. L.

Recovery of Sulphur from Flue Gases. W. Francis and G. H. Lepper. (Engineering, 1951, vol. 172, July 13, pp. 36–37). The authors examine the possibility of recovering the large quantities of sulphur contained in flue gases discharged into the atmosphere by power station boiler houses and other large coal-burning or coking installations. Continental methods and practices are reviewed. The authors suggest that the installation of recovery plants might be more economical than that of plants of equivalent output used for mining and treating anhydrite.—M. D. J. B.

Experiences with the Escher Metallic Recuperator on High-Temperature Furnaces. H. Escher. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 39–46). Operating experience obtained at the Port Kembla Steelworks of Australian Iron and Steel, Ltd., on furnaces equipped with Escher recuperators, is described. Performance figures are given for a 10-in. mill billet-heating furnace, equipped with recuperators, which has been in operation for some time. A general description, including data on furnace operation, is given of the billet-heating furnace for the new rod and strip mill which commenced operation in October, 1949. Heating characteristics of coke-oven gas and blast-furnace gas as fuel for firing are compared. It is shown that thicker stock can be more satisfactorily heated in a single zone by using blast-furnace-gas firing rather than coke-oven gas. A design for a single-zone blast-furnace-gas-fired furnace is discussed.

The Deleterious Effects of Sulphur in Fuels. P. F. Corbett. (British Coal Utilisation Research Association, Monthly Bulletin, 1951, vol. 15, May, Review Series No. 103, pp. 169–181). This is a review of the literature from 1944 to 1950 with 112 references.—R. A. R.

Modern Coal Cleaning in the Pittsburgh Area. R. P. Bremner. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author enumerates the more important factors affecting the cleaning of bituminous coal, and shows how these problems have been solved in the modernization of existing plants and in the planning of new installations. An urgent need exists for better methods and equipment in certain phases of coal preparation, particularly in the screening and cleaning of fine coal, and lines for further research are suggested.—G. F.

The Design of Dense Media Coal Washers with a Description of the Ridley-Scholes System. F. F. Ridley. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 449–473). Types of dense media used, the control of washing, and recovery systems are discussed with a description of the Ridley-Scholes system employing a semi-stable medium of magnetite coal and shale in a shallow bath. A plant of 600 tons/hr. capacity is under construction in Britain.—A. G.

The Humphreys Spiral Concentrator for the Purification of Coals below 6·35 mm. J. S. Hubbard, W. E. Brown, and M. Welker. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 474–481). These concentrators are usable when most of the impurities are above 100 mesh and a reasonable difference in density between 10 and 65 mesh exists.—A. G.

The Theory of Flow in a Cyclone. M. G. Driessen. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 482–495). The influence of turbulence and its mathematical interpretation are considered. From equations derived and measurements of static pressures in a plane cyclone, tangential speeds are calculated.—A. G.

The Application of Hydrocyclones in Coal Washers. C. Krijgsman. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 496–511). The use of hydrocyclones as thickeners, classifiers, and washers is discussed.—A. G.

Study of Some Centrifugal Separation Plants. P. Belugou and A. Ouyahia. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 512–520). Results for helical and cylindrical types are compared.—A. G.

Dense Media Washing on a Trough Belt Conveyor. J. R. Schönmüller. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 521–540). Belt speed is adjusted so that the medium is at rest in relation to it, belt length being governed by speed of sedimentation. A scheme of treatment and results from a test installation are given.—A. G.

Behaviour of Coal Fines during Treatment in Cyclones, Thickener, and Separator. G. Burton. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 541–547. The effect of density of separation, other factors being constant, is reported. A tentative scheme of treatment using only cyclones is advanced.—A. G.

Experimental Study of a Cyclone Purifier. P. Belugou and S. de Chawlowski. (Revue de l'Industrie Minérale, 1951, vol. 31, Mar., pp. 556–567). A comparison of laboratory and pilot-plant tests indicates that for similar outlet diameters and a partition density close to that of the entering medium, other factors such as cone angle have little effect.—A. G.

Tests on a New Dense Liquid Jig. Baucher, Belugou and Colin. (Revue de l'Industrie Minerale, 1951, vol. 31, Mar., pp. 568–577). Results on a pilot plant giving three products in which separation is effected in horizontal currents of media of varying densities indicate that a rate of 100 tons/hr. should be easily attained on a 2 × 3·6 m. jig. —A. G.

The Vacuum Jig. J. A. Brusset. (Revue de l'Industrie Minerale, 1951, vol. 31, Mar., pp. 588–592). The principles, necessary equipment, and technical advantages are discussed The method is useful for coals of high fines content or where the cleaned coal must have low moisture.—A. G.

Statistical Data on the Mechanical Cleaning of Bituminous Coal in the United States. R. L. Anderson. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 783–792). Details of equipment, methods of exploitation and the cleaning of different types of coal are given with tables of production figures.—A. G.

Comparison of Coal Cleaning Processes. W. R. Chapman. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 793–800). Baum, Chance, Ridley Scholes, Tromp, and other washers are studied and classified according to the size of coal treated. Tables give the density range for which each washer may be used.—A. G.

Comparison of Dense Media Washing Plant and the Jig Washer. O. van de Loo. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 801–808). For a mine producing domestic coal costs were 25·6 (Dutch) cents/ton for heavy media and 18·8 cents/ton for jig washing, installation costs being similar.—A. G.

Performance and Efficiency of British Coal Preparation Plants. A. Grounds and L. W. Needham. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 808–827). The different processes used and the determination of efficiency is described. Information on the cost of the various processes is given.—A. G.

Influence of Rationalization at the Face on Cleaning Results and Installations, in particular, Gravity Washing. G. A. H. Meyer. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 845–852). Mechanical coal cutting increases impurities, fines, and moisture in the coal, and the washing plant must be made less sensitive to changes in coal composition. Gravity washing is difficult in the presence of fines.—A. G.

Some Reflections Suggested by 30 Years in the Construction of Coal Washers. C. Wolf. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 853–864). Adequate maintenance and planning can overcome the need for reserve circuits. Washers are often complicated due to consumers demanding excessive diversity. A theoretical study of washing installations is made.—A. G.

Technical and Economic Repercussions of the Concentration of the Mechanical Preparation of Coal. R. Blondelle. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 828–844). Concentration is advantageous when output is large and normally leads to a reduction in transport costs with easier maintenance.—A. G.

Central Cleaning Service for Combustibles in the Saar Mines. J. Baucher. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 865–881). The organization, structure, and activities of this service are reviewed.—A. G.

New Outlook on the Treatment of Large Saar Coal. R. Lehner. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 882–897). The present system and the trend towards mechanical treatment are discussed. A general scheme giving : (*a*) Two products and (*b*) three products is outlined, and a comparison made between the conditions of separation by hand sorting and mechanical treatment.—A. G.

Problems of Coal Washing in the Western United States. W. M. Bertholf. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 898–910). From 1947 there has been a decline in coal washing due to the increasing use of natural gas. Two thirds of all coking coal is washed. Examples of characteristic coals washed in different States are given.—A. G.

Economic Aspects of the Mechanical Treatment of Ores and Raw Coals. P. Seyer. (Revue de l'Industrie Minérale, 1951, vol. 31, May, pp. 911–916). General formulæ for the sale of ore, weight efficiency, and industrial efficiency are discussed and applied to the case of a combustible. The factor 'value of utilization' is calculated for a particular combustible.—A. G.

New Coking Plant at Nantgarw. (Iron and Coal Trades Review, 1951, vol. 163, Sept. 21, pp. 645–649). **Nantgarw Coke Oven and By-Product Plant.** (Colliery Guardian, 1951, vol. 183, Sept. 20, pp. 319–326). This new battery of 48 ovens will produce 1100 tons of coke per day. The ovens are Simon-Carves standard underjet, twin-flue compound type, with triple compartment regenerators. The ovens are 44 ft. 7 in. long, 12 ft. 6 in. high with a mean width of 18 in. Descriptions are given of the pushing machine; by-product, boiler, and coal- and coke-handling plants; and the power supply.

New Coke Oven Installations. (Electrical Review, 1951, vol. 149, Sept. 7, pp. 463–467). A description, with emphasis on the electrical equipment, is given of the new battery of 54 Becker ovens recently installed at the Fell coke works of the Consett Iron Co., Ltd. This battery carbonizes about 15,000 tons of coal per week.—R. A. R.

The Coke Ovens at Iscor Works, Vanderbijl Park. (Iscor News, 1951, vol. 16, Aug., pp. 680–685). A description with ten illustrations is given of the new battery of 54 coke ovens which started production in 1950 at the works of the South African Iron and Steel Industrial Corp., Ltd. The ovens are 40 ft. long × 13 ft. × 16 in. Each oven is charged with about 17 short tons of coal every 17 hr. About 850 short tons of coke are produced daily from 1290 tons of coal. The battery has additional gas mains and fans to recirculate the gas evolved during carbonization; this improves the yield of certain by-products.—R. A. R.

Handling of Coal to Minimize the Effects of Oxidation. P. J. Conners. (American Institute of Mining and Metallurgical Engineers; Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 137–145). Oxidation of coal begins as soon as it is mined. This reaction is usually accompanied by poorer coking properties and some change in the heating and combustion properties of the coal. The rate of oxidation increases rapidly with temperature, but also decreases rapidly as oxidation proceeds. Coal that has reached a temperature of 150° F. will proceed to the ignition point unless it is moved. Details are given of the effect of storage on the coking properties, and means of measuring loss of coking power. Storage methods are surveyed and suggestions made; coal should be stored in compacted layers, with as little separation of sizes as possible.—T. E. D.

Metallurgical Tests for Control of Coal and Coke Quality. R. C. Weed. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 145–161). Work at the American Steel and Wire Co. at Duluth, on the quality of coal delivered and stored, showed the existence of a close relationship between agglutinating numbers and CO_2 and CO percentages in gases from the tube distillation test. In addition, these factors were related to percentage of blast-furnace coke to total coke produced, fuel index, and blast-furnace coke practice and production. The tests established for determining the coking and weathering properties of coal were a modified Marshall-Bird agglutinating test, an oxygen-bomb oxidation test, and a bromine-number self-heating test. Later, agglutinating numbers were estimated more rapidly using a test based on their equivalence to free swelling index values. These tests, and the Chairton tumbler test, are described briefly.—T. E. D.

Maintenance of Coke Ovens at Gary during the Steel Strike in 1949. G. A. Fort. (American Institute of Mining and Metallurgical Engineers; Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 162–164). The general policy of the Carnegie-Illinois Steel Corporation at Gary, Ind., was to shut down all batteries as soon as possible, blank off all ascension pipes and gas-suction mains at the by-product valves, and leave all ovens sealed and fully charged. The flues were maintained at a temperature greater than 1800° F. to prevent damage to the brickwork.—T. E. D.

Standby Maintenance of Coke Ovens at Indiana Harbor, Inland Steel Company. H. A. Hager. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 164–165). The maintenance of six batteries of coke ovens in two separate and complete plants is involved. Two batteries are worked, giving sufficient fuel to operate themselves, to keep the four idle batteries hot, plus a surplus for general plant consumption. Non-producing batteries are pushed empty, and flue temperatures are maintained at 1900–1950° F., oven lids and doors are sealed, and mains are blanked off.—T. E. D.

Maintaining Coke Ovens during Strike Periods, Jones and Laughlin Pittsburgh Plant. F. L. McIntire. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 166–171). The subject is divided into three phases: (1) Preparation for the discontinuance; (2) discontinuance of operations; and (3) maintaining the ovens in operating condition during the period of idleness. The procedure at the Pittsburgh plant is described.—T. E. D.

Coal-Carbonizing Facilities at Clairton Works. J. McIntosh. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 172–179). Operations at the Carnegie-Illinois Steel Corporation's plant at Clairton, Pa., during the 1949 steel strike are described. It was decided not to leave the ovens empty and hot during the shutdown, because of damage that would occur through loss of carbon deposited on the door linings and walls; this would be especially serious in the case of the older batteries. Leaving the batteries charged and sealed was not considered sufficient protection. Therefore, the ovens were pushed and recharged on a greatly reduced schedule. Normally, about 1920 ovens are pushed each day. During the strike period, about 50 ovens a day were pushed.—T. E. D.

Shutting Down Coke-Oven Batteries, Campbell Coke Plant. A. H. Parthum. (American Institute of Mining and Metallurgical Engineers; Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 179–180). At the Campbell Coke plant of the Youngstown Sheet and Tube Co., comprising six Koppers batteries of 51 ovens each, coke is left in the ovens when it is necessary to shut down a battery. Details of shutdown procedure, maintenance and flue temperature during shutdown, and recharging are given.—T. E. D.

Maintenance of Coke Ovens during Shutdowns, Youngstown Sheet and Tube Co., Indiana Harbor. E. W. Steinweg. (American Institute of Mining and Metallurgical Engineers; Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 181–183). At this plant, there are two batteries of 60 ovens. When idle, temperatures were maintained at 1940° F. as opposed to 1600° F. in earlier shutdowns, fewer linings failing at the higher temperature. The formation of clinker during a shutdown is discussed.—T. E. D.

Results of Joint Operation of Blast Furnace, Coke Ovens and Power Plant at the Watenstedt Works. P. Rheinländer. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Aug. 1, pp. 715–716). Output figures are quoted from which it follows that substantial fuel economies or better utilization of the coke-oven products have resulted from the joint operation of plant left after the post-war dismantling.—J. G. W.

Cleaning Ferromanganese Blast-Furnace Gas. C. A. Bishop, A. H. Brisse, R. G. Thompson, C. R. Liebel, and W. A. Swaney. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The authors describe the development of a practical method for removing and disposing of the fume which comprises about 80% of the solid matter in ferromanganese blast-furnace gas. The preliminary laboratory work is first considered, followed by the operation of a pilot plant. The gas to be treated first enters a spray cooler, in which it is essential that all the spray water is evaporated, and is then passed through an electrical plate-type precipitator. The collected fume is then burnt in a rotary kiln and briquetted, or may be leached if necessary to reduce the alkali content. The pilot plant has worked very successfully, and a plant capable of dealing with 135,000 standard cu. ft./min. of gas has been designed.—G. F.

Application of Superimposed Precipitators. R. E. Touzalin. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 81–90). Three installations of tower scrubber and superimposed electrostatic precipitator cleaning units are described briefly. Such gas-cleaning units provide a means of conserving ground space, and were originally developed for this purpose. The two latest installations by

Arthur G. McKee and Co., Cleveland, Ohio, are also described, in each case three units being used to clean the gas of two blast-furnaces. In one, each unit combines an 18-ft. dia., single stage, three-tile-bank tower scrubber with a precipitator unit having 168 tubes 12 in. in dia. and 15 ft. long. The rated capacity of the three cleaners is 235,000 cu. ft./min. of blast-furnace gas. The other installation has static-tower type gas washers, 21 ft. in dia. and 65 ft. high, and precipitator units 26 ft. 6 in. in dia., provided with 224 tubes 12 in. in dia., and 15 ft. long. The rated capacity of the three cleaners is 300,000 cu. ft./min. of gas. Diagrams of plant and layout are given.—T. E. D.

Modern Blast-Furnace Gas Cleaning. G. P. Burks. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 91–103). The present arrangement of the cleaning system for the gas from the 12 blast-furnaces at the Gary Works of the Carnegie-Illinois Steel Corporation, and the modernization programme in operation, are briefly described. The trend is towards more efficient primary dust catchers, followed by static primary washers and, for fine cleaning, which is considered very important, the electrical precipitator. Washers and cleaners described include the static tower washer, rotary tower washer, electrical precipitator, rotary disintegrator and the Theisen washer.—T. E. D.

Gas-Washer Developments. H. O. Johnson. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 104–111). This paper is concerned with stationary disintegrator washers at the Donora blast-furnace plant of the American Steel and Wire Co. The first washer, installed in 1941, has a capacity of 18,000 cu. ft./min., and consists of a tile-bank washer, stationary disintegrators, and moisture eliminator section. Details are given of the construction, operating difficulties and maintenance of this unit. The second washer is of essentially the same design, but with a capacity of 30,000 cu. ft./min.—T. E. D.

Disintegrators for Fine-Cleaning Blast-Furnace Gas. O. R. Rice and C. G. Bigelow. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 111–118). The version of the Theisen disintegrator (rotary type) produced by the Freyn Engineering Co., Chicago, is described. It is used to fine-clean gas to less than 0·01 grain/cu. ft. After cleaning in the disintegrator, the gas passes through a rubber-lined cyclone moisture eliminator. Apart from its high power consumption, the Theisen disintegrator has the following advantages over other fine-cleaning methods: (1) Moderate installation costs; (2) it offers facilities for boosting gas pressure; (3) it is not sensitive to the quality of the primary washed gas; (4) it is used successfully to clean ferromanganese gas.—T. E. D.

A Continuous Dry Process for the Removal of Hydrogen Sulphide from Industrial Gases. F. G. Audas. (Coke and Gas, 1951, vol. 13, July, pp. 229–234). A new process, in the pilot-plant stage, is being developed by Audas and Thomson, Ltd. under Pat. No. 653,317. The process utilizes the reaction $2H_2S + SO_2 \rightarrow 2H_2O + 3S$ catalysed by alumina. The alumina is continuously circulated, being regenerated at 500° C. A flowsheet and description of the plant are given. Its capacity is 700 cu. ft./hr., giving contact times of 3 to 7 sec. Data on the recovery of sulphur, life of alumina, and cost are given. A cost of 1·2*d.*/100 cu. ft. is quoted, but this does not include capital or maintenance costs, or possible credit from sale of sulphur or other by-products.—T. E. D.

TEMPERATURE MEASUREMENT AND CONTROL

Total Radiation Pyrometers. E. J. Burton, R. Mayorcas, W. H. Pritchard, M. Michaud, and M. Rivière. (Comité International d'Études sur le Rayonnement des Flammes; Chaleur et Industrie, 1951, vol. 32, Aug., pp. 205–212). Two types of total radiation pyrometer were tested. The first instrument, the mirror or Kipp pyrometer, employs a gilded mirror for concentrating the energy received at a focus. The second instrument is the diaphragm or Michaud pyrometer. Both pyrometers are used in conjunction with Moll thermopiles, and both are described in detail. Five pyrometers of each type were installed in an experimental black body calibrating furnace (range 1000–1650° C.), which is described. Their calibrations were checked after a series of preliminary and industrial trials. The results were very satisfactory. T. E. D.

Temperature Measurement of Liquid Steel in Open-Hearth Furnaces with an Immersion Pyrometer. K. Guthmann. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 728–730). A description is given of an immersion platinum/platinum–rhodium thermocouple pyrometer. The long tube is double-walled and of mild steel, covered with a glass-wool/corundum/water-glass layer for heat protection. It is carried on a two-wheeled trolley, running on rails up to the furnace door. The pyrometer head is an ingot iron tube with an inner fireclay lining to support a translucent quartz tube which contains the actual thermocouple. The temperatures read when the pyrometer is immersed have been compared with readings taken simultaneously with the new Bioptix II colour pyrometer focused on a stream of steel from a sample spoon. There was good agreement.—J. P.

REFRACTORY MATERIALS

An X-Ray Study of Spinels in Relation to Chrome-Magnesite Refractories. K. W. Andrews. (Transactions of the British Ceramic Society, 1951, vol. 50, Feb., pp. 47–74). Lattice parameter and interplanar spacing data are provided for ten different oxides with the spinel crystal structure. The spinel constituent in chrome ores and chrome-magnesites may be regarded as a solid solution of certain pure end-members. The lattice parameter is calculated assuming Vegard's law to apply, and the value obtained compared with the measured parameter, according to the method suggested by Rait. Agreement is considered to be reasonably good and to confirm that the method is a valid way of working out the constitution of the solid solution spinels using X-ray and chemical data in conjunction. In general, the calculation assumes a balanced spinel, but in certain cases the presence of some α-Al_2O_3 in solid solution appears to be a justifiable conclusion from the fact that the parameter calculated on the basis of a balanced spinel is higher than that actually observed. In many cases the amounts of α-Al_2O_3 would be quite small compared with the total Al_2O_3 content.

The Abrasion Resistance of Refractory Bricks. J. Mackenzie. (Transactions of the British Ceramic Society, 1951, vol. 50, Apr., pp. 145–174). A description is given of a method used to determine the abrasion resistance with a Wheelabrator shot-blasting machine of the type used in peening the leaves of heavy vehicle springs. Results are presented for carbon, fireclay, basic, silica, and miscellaneous refractory bricks. The investigation—to compare the relative abrasion resistance of carbon and fireclay blast-furnace stack refractories—has shown that carbon is, on the whole, superior to fireclay. Recognizing the difficulties of abrasion testing, attempts were made to correlate the abrasion resistance with the hardness, apparent porosity, bulk density, cold crushing strength, and nominal transverse breaking stress of the bricks. The best correlation was found with the nominal transverse breaking stress, which is in agreement with previous researches on abrasion of refractory bricks.

Refractory Products. L. Halm. (Métaux et Industries, 1950, No. 1, pp. 3–10; No. 2, pp. 39–49; No. 3, pp. 76–81). Refractory materials are reviewed and are divided into three groups: (1) Products of silica, $SiO_2 > 91\%$, $Al_2O_3 < 3\%$; (2) siliceous products, SiO_2 85–93%, $Al_2O_3 > 5\%$; and (3) products with a clay base, Al_2O_3 15–44%. The manufacture of refractory materials and methods of testing are given, and the characteristics and properties of a number of products are tabulated. Materials with a clay base, essentially the hydrosilicate kaolinite, are considered in some detail, and data are given of the transformation by heating to the various silicates of aluminium. In connection with silica products, the allotropic transformations of silica are discussed. Basic refractories, in particular magnesite, chrome-magnesite, forsterite and dolomite are surveyed, and the insulating nature of refractory bricks is mentioned. Finally, the uses of refractory materials are reviewed.—T. E. D.

Influence of the Texture of Ceramic Materials on their Thermal Expansion: The Reduced Expansion on Tranformation in Quartz and Crystoballite. P. Munier. (Silicates Industriels, 1950, vol. 15, No. 4, pp. 67–76; No. 5, pp. 91–95). Reasons are given why the common method of measuring the proportions of siliceous materials in a ceramic product by observing the expansions at the transformation temperatures

is unsatisfactory. A striking similarity was found between the residual expansion effect and the residual distortion after bending tests. It is suggested that when the $\alpha \rightleftharpoons \beta$ transformation takes place in a grain of quartz or crystoballite the expansion is so sudden and large that the intergranular bonds are often ruptured, and strains are set up which may cause reorientation of many grains, and hence the permanent change. Two classes of material are distinguished : Those in which the structure is open, the bonds weak, and the grains therefore free from strain ; and those with close structure and much binding material, in which the low-temperature transformations must cause strains which it is impossible to relieve. A better quantitative method of analysis by expansion depends on making the test brick from the sample grains ground with alkali silicate or chalk flux.—N. MCE.

Fundamental Investigation of Steel Plant Refractories Problems : 1.—Phase Relations in the System $2CaO.SiO_2$–$CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO. A. Muan and E. F. Osborn. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The investigation described in this paper is concerned with phase equilibria in part of the system CaO–FeO–Al_2O_3–SiO_2, a system of four of the components of steelplant refractories and slags. The present study extends previous work to the lower-silica system $2CaO.SiO_2$–$CaO.SiO_2$ –$2CaO.Al_2O_3$–SiO_2FeO. The system contains three quaternary invariant points, which have similar liquidus temperatures of 1175–1200° C. and similar alumina contents of about 5%. Phase equilibrium data are also presented for the system $2CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO, which constitutes one face of the tetrahedral system, the data necessitating a slight change in the previously published diagram for the system $CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO. An equilibrium diagram for the binary system $2CaO.Al_2O_3.SiO_2$–$2CaO.FeO.2SiO_2$ is also given.—G. F.

Rammed Refractory for Cupola Linings. J. Krol. (Przeglad Odlewnictwa, 1951, vol. 1, Apr., pp. 113–117). [In Polish]. The economic advantages of rammed refractories instead of bricks are discussed.—V. G.

Comparison between Brick-Lined and Rammed Ladles for the Pouring of Open-Hearth Steel. W. Schleicher. (Stahl und Eisen, 1951, vol. 71, July 5, p. 708). The results of a questionnaire to six open-hearth steelworks, each of which uses simultaneously brick-lined and rammed ladles, has shown that the latter consumes 1·1–1·5 times as much refractory as the former, but that the longer life of the rammed lining results in a saving of approximately DM 0·50/ton of steel as compared with brick linings, without detriment to the cleanliness of the steel.—J. P.

Refractories. W. O. Williamson. (Society of Chemical Industry of Victoria, 1949, vol. 49, No. 1, pp. 947–950). The author discusses in general terms different types of refractory, their characteristics and applications.—J. A. L.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Pig Iron Production—New Blast Furnaces at Consett. (Electrical Review, 1951, vol. 149, Sept. 14, pp. 515–520). Of three new blast-furnace installations at the works of the Consett Iron Co. Ltd., one is complete and in commission. It is here described with special reference to the electrical equipment. The furnace is 180 ft. high and the hearth 20 ft. in dia. Blast-furnace gas is finally cleaned in Lodge-Cottrell electrostatic distributors ; three of these are in operation at a time and handle 9 million cu. ft. of gas/hr.—R. A. R.

Blast-Furnace Controlled Split-Wind Blowing at Algoma Steel Corp. W. O. Bishop. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 78–82). Split-wind blowing of blast-furnaces is defined as the delivering of wind simultaneously to two or more furnaces from a common main as supplied by one or more units of blowing equipment. After a critical review of this practice in the U.S.A., Great Britain, and Germany, the author describes the development and present layout of the Algoma Steel Corp. Layout drawings and furnace operating data are given. It is suggested that split-wind blowing offers advantages, technical and economic, where a number of small furnaces are in operation simultaneously.—M. D. J. B.

The Kinetics of the Reduction of Iron Oxide above 1400° C. T. E. Dancy. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 17–24). An apparatus has been developed for the study of the very rapid reduction of FeO and Fe_3O_4 by carbon in molten pig iron. Oxide attack of the refractory was prevented by using a spinning crucible and the reaction was followed by cinematographic recording of a low-inertia pressure gauge. The apparent activation energy of the reduction of FeO is −43,100 cal./mol, and of Fe_3O_4 is −37,300 cal./mol. The FeO reduction behaved as if of the first order, but only the initial part of the Fe_3O_4 reduction behaved thus. Temperature coefficients determined from activation energy and from ' order of reaction ' curves showed reasonable agreement.

The Reduction of Metallic Oxides by Solid Carbon. P. V Gel'd, V. G. Vlasov, and N. N. Serebrennikov. (Doklady Akademii Nauk, U.S.S.R., 1951, vol. 78, No. 4, pp. 693–696). [In Russian]. The mechanism of direct reductions is discussed. On the basis of their experiments the authors consider that the direct reduction takes place in two steps : (*a*) $MeO + CO = Me + CO_2$ and (*b*) $C + CO_2 = 2CO$. Experiments were made in the reduction of chromic oxide and manganous oxide under a vacuum of 10^{-5} mm. and in the temperature ranges of 850–1150° C. and 950–1160° C. respectively. Apparent activation energies of 49,400 cal. (chromic oxide) and 47,000 (manganous oxide) were obtained, which are of the same order as for the graphite and carbon dioxide reaction. The velocity of the reduction of the two oxides is controlled by the slow reaction of gasification of carbon.—V. G.

Modern Blast-Furnace Equipment. T. H. Stayman. (Times Review of Industry, 1951, July, pp. 20–22 ; Aug., pp. 25–26). Factors in the layout of blast-furnace plant are outlined and methods of ore pretreatment are surveyed. The design of stock-house bins, types of hoist, and methods of bell operation are discussed. Mention is made of gas cleaner design and types of hot metal ladle and slag ladle. Treatment of fines by agglomeration and sintering is described, and reference is made to a rotary sinter cooler, which has a capacity of about 100 tons/hr.—T. E. D.

Trends in Blast-Furnace Practice. R. P. Towndrow. (Metallurgia, 1951, vol. 44, July, pp. 17–21). Although in this country the average hearth diameter of blast-furnaces has increased, it is unlikely to exceed 23 ft., because of capital costs. There has been increasing use of carbon refractory linings, and more attention is paid to ore preparation, and there is some high top-pressure operation.—E. T. L.

Statistical Analysis of Blast Furnace Production Data. D. S. Leckie. (Journal of Metals, 1951, vol. 3, June, pp. 443–444). The large number of variables encountered in blast-furnace operation make it one of the industry's most complicated processes, and the author shows how the individual effects of some of these variables can be evaluated by statistical analyses of blast-furnace production data. Results obtained using the ' multiple correlation ' and ' analysis of variance ' methods are quoted, and the applicability and limitations of such statistical analyses are discussed.—G. F.

The Effect of Sinter on Blast-Furnace Production as Determined by Analysis of Daily Operating Data. W. E. Marshall. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author discusses the results obtained by a statistical analysis of blast-furnace operating data, made to determine the effect of sintered ores on the production rate. The data are divided according to burdens containing 47·7% and 61·9% of sinter ; with the latter, the peak production rate is somewhat lower but occurs at a lower blowing rate. As most sinters reduce more slowly than ore, this is felt to be due to a large portion being reduced deeper in the furnace and causing an increased solution loss. In order to obtain the full potential benefit of sinter further effort must be made to determine the best methods of using and making it, and suggestions for further tests are given.—G. F.

The Pig Machine at Wisconsin Steel Works. R. P. Wheatley. (American Institute of Mining and Metallurgical Engineers ; Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 127–130). At the Wisconsin Steel Works, Chicago, two pig machines are in operation, each having two strands or chains. The machines, their operation, and their maintenance are briefly described. Pigs of average weight 40 lb. are produced in moulds made from iron of the following composition : Si 1·50–2·00%, S < 0·035%, P < 0·150%, and Mn 0·75–1·00%. Between operations the moulds are sprayed with a coating of burnt dolomite, about 8 lb. being used per ton of iron pigged.—T. E. D.

Blowing Out Carbon-Bottom Furnaces, Republic Steel Corporation. H. F. Dobscha. (American Institute of Mining

and Metallurgical Engineers : Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, p. 209). Two blow-outs, using the domestic coke method followed by drenching, caused considerable erosion of carbon. With the same method, followed by raking out after 24 hr., having used no water, disintegration of carbon was not serious.—T. E. D.

Production of High-Purity Iron and Iron Alloys on a 25-lb. Scale. B. E. Hopkins, G. C. H. Jenkins, and H. E. N. Stone. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 377–383). The method and equipment developed in the National Physical Laboratory to produce iron and iron alloys of high purity as 25-lb. ingots are described. Starting with a selected batch of Swedish iron, the purification procedure is carried out on the iron in the molten condition in two main stages : (*a*) Oxidation of a number of impurities and removal of the products of oxidation, and (*b*) a vacuum treatment for degassing, followed by reduction of oxygen to a low level by dried hydrogen. The experience gained in operating the process over a period of time is recorded. Chemical analyses of the iron before treatment, of the oxidized iron, and of the reduced iron, are given. Some investigation has been necessary into methods of analysis and notes on these are given in an Appendix by H. G. Short.

TREATMENT AND USE OF SLAGS

Preparation of Concrete Roofing Tiles from Slag Sand and Blast-Furnace Cement by Dry Pressing. K. Trautmann. (Stahl und Eisen, 1951, vol. 71, June 21, pp. 678–679). A new process is described for the preparation of concrete roofing tiles by dry pressing, using slag sand and clay as aggregate. The methods of working and the behaviour of the clay is discussed. The new process can compete with the present methods of making roofing bricks and tiles, and appears to offer a new use for blast-furnace slag.—J. P.

Production and Application of Ytong Concrete. A. Laubenheimer. (Zeitschrift des Vereines Deutscher Ingenieure, 1951, vol. 93, Aug. 1, pp. 718–719). This is a short note on the Swedish patent Ytong light concrete made at the Watenstedt works (Germany) from fly ash from the power station, crushed blast-furnace slag, and lime. Dimensions and physical properties are quoted. The application is chiefly as insulating material for housing.—J. G. W.

DIRECT PROCESSES

Direct Reduction of Iron Ore using the Fluidized Solids Technique. M. Tenenbaum and C. M. Squarcy. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The authors describe an investigation into the possibility of direct reduction of iron ores and other iron-oxide-bearing materials, by the ' fluidized solids ' technique, in which finely divided solids are suspended in a moving gas stream. In most of the experiments a fluidized system was obtained and some reduction was effected, but the silica content in many cases was too great for the product to be used in the open-hearth furnace, whilst the expense prevents the use of the method to produce a blast-furnace charge material. The process affords an effective means of roasting iron oxide materials to make them amenable to magnetic separation.—G. F.

Progress and Setbacks in Sponge Iron Making. S. Eketorp. (Teknisk Tidskrift, 1950, vol. 80, Dec. 9, pp. 1131–1135). [In Swedish]. Swedish and Canadian experiences in making sponge iron are reviewed. The tendency of the charge to stick to the furnace walls represents one of the main obstacles, and this has been overcome in the Wiberg-Soderfors process since the exothermal reduction with carbon monoxide facilitates the maintaining of a lower wall temperature.—B. S. E.

PRODUCTION OF STEEL

Raw Material Supplies, Metallurgical Load and Output in the Iron and Steel Industry. T. P. Colclough. (Iron and Coal Trades Review, 1951, vol. 163, July 13, pp. 67–71). This article summarizes the paper given by the author to the Fifth Junior Steelmaking Conference of B.I.S.R.A. It is shown that the main effect of the increased quantity of pig iron which must be used in steel manufacture, will be to increase the weight of ore required and the weight of slag formed, and steps to counterbalance these difficulties are considered. These include the provision of more tilting furnaces, use of the flush-slag process, and pre-treatment of the pig iron. The increase in pig iron in the charge will also make the problem of sulphur removal more difficult, and desulphurization of the pig iron appears to be essential.—G. F.

World's Most Modern Integrated Steelworks. (Iron and Coal Trades Review, 1951, vol. 163, July 20, pp. 143–146). **The Margam and Abbey Steel Works.** (Engineer, 1951, vol. 192, July 27, pp. 112–115). **Margam Project Reaches Fruition.** (Times Review of Industry, 1951, Aug., p. 34). **Britain's Newest Steelworks Opened.** (Metallurgia, 1951, vol. 44, Aug., pp. 63–68). **South Wales Steel Strip Project in Production.** (Machinist, 1951, vol. 95, July 28, pp. 1135–1137). **Margam and Abbey Works.** (Iron and Steel, 1951, vol. 24, Aug., pp. 361–370). **The Steel Company of Wales.** (Mechanical Handling, 1951, vol. 38, Sept., pp. 356–359). These articles give a concise description of the new Margam and Abbey Works, officially opened on July 17, 1951. The many unique features of these works, which when completed will have an estimated annual steel production of 1½ million tons, are briefly described. Layout drawings and a number of photographs are given together with considerable technical and operating data.—M. D. J. B.

Oxygen as a Means of Increasing Bessemer Production. W. G. McDonough. (American Iron and Steel Institute. May 23–24, 1951, Preprint; Industrial Heating, 1951, vol. 18, Sept., pp. 1595–1602, 1680). An account is given of experiments with oxygen-enriched blast in a 28-ton acid bessemer converter at the National Tube Co., McKeesport, made to determine the most efficient practice for melting an increased amount of scrap. The main aspects studied were the effects of variations in the volume, rate, and time of oxygen input, the effect on the slag and steel quality, and the overall blowing time required. The optimum conditions are obtained with 1500 cu. ft./min. of oxygen for 4 min., which enables the scrap charge in a 60,000 lb. blow to be increased by about 4000 lb.—G. F.

The Use of Oxygen/Carbon-Dioxide instead of Air in the Final Stage of the Basic-Bessemer Process. Bo Kalling. F. Johansson, and L. Lindskog. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 337–343). The paper describes the results of a number of experimental blows in a 14-ton basic Bessemer converter at Domnarfvet Iron Works, in which the charges were dephosphorized with O_2/CO_2 instead of air in order to reduce the nitrogen content of the product. It was reduced to about 0·006% in the finished steel, as against about 0·012% by normal air blows. A further reduction to 0·003–0·004% was found to be possible by using oxygenated air for the preliminary blowing. Equal parts of oxygen and carbon dioxide produced approximately the same temperature conditions as air-blowing, but the blowing time was slightly shortened. There was no apparent increased injury to the converter bottom. The gas consumption was about 1200 cu. ft. per metric ton of pig iron, which at a price of 2*s.* per 1000 cu. ft. corresponds to 2·4*s.* per ton. Another advantage of the final blowing with O_2/CO_2 was that the pouring temperature could be adjusted to whatever was most suitable for the mode of pouring and the quality of the steel. By using more than about 50% of oxygen in the gas mixture, more scrap could be remelted during the blowing. If pure carbon dioxide was used for the final blow, the iron losses in the slag could be reduced.

Instrumentation and Automatic Reversal System of Open-Hearth Furnaces. C. E. Mortensen. (Blast Furnace and Steel Plant, 1951, vol. 39, May, pp. 533–539). This article describes the operation of the automatic reversal system applied to each of 30 open-hearth furnaces in the Lackawanna N.Y. plant of Bethlehem Steel Company. The panel cubicles are described. Details are given of the valve manifold assembly, the rotary cam switch, combustion air flow control, liquid fuel flow control, atomization steam pressure control, furnace pressure control, the reverse cycle, and bath temperature measurement.—J. P. S.

Additional Firing with Tar Oil to Economize in Long-Distance Gas. H. Clees. (Stahl und Eisen, 1951, vol. 71, June 21, pp. 673–678). A report is made on the design and development of gas and hot oil burners with which, by the substitution of oil for large proportions of mains gas, steel output can be maintained in the event of gas failure, without costly rebuilding of open-hearth furnaces. Tests have shown that the life of acid roofs is shorter under these conditions than when firing with coke-oven gas. The high heating power of the oil flame demands the use of an all-basic roof and

of special checker bricks. The high price of these, however, tends to offset their better refractoriness. The costs for an all-basic furnace are justified only by marked increases in output.—J. P.

Open Hearth Charge Ores. J. J. Golden and H. E. Warren, jun. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The authors describe trials with both 'as mined' and 'prepared' charge ores, to evaluate their effect on open-hearth production rates. A review of the results indicates a variation of about 12% in the production rates obtained with the various types of charge ore, although a direct comparison is difficult due to variations in operating conditions. Hematite ore in hard, dense lumps is felt to be the ideal charge ore and the suitability of other ores depends on a number of factors, including furnace size, bath depth, firing rate, and furnace temperature when the ore is charged. Much work remains to be done on processing the poorer grades of ore to provide a suitable charge ore which is consistent in size and structure.—G. F.

Significance of Air Temperature in Open Hearth Operation. J. S. Marsh. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author describes the use of a multiple shield high-velocity suction pyrometer in a study of the significance of preheated air temperature in open-hearth furnace operation. The preheat temperature has a considerable effect on the charge-to-tap time, the latter factor being roughly inversely proportional to the air temperature. A study of operating records indicates that most furnaces are operated with air preheat temperatures lower than the optimum, and the author recommends that special precautions to prevent air infiltration, which is the principal factor determining the air temperature, should be taken.—G. F.

Instrumentation and Control for Mixed Fuels and Oxygen in Open-Hearth Furnaces. M. J. Conway and E. H. Cauger. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 106–114). This paper gives a description of the instrumentation and control equipment installed on the open-hearth furnaces at the Steubenville Works of the Wheeling Steel Corp. where coke plant tar, fuel oil, and coke-oven gas are used. Technical and operational data are given on fuel oil temperature and viscosity control, furnace pressure control, fuel control and summarization, oxygen and air summarization, and atomized steam control. Control performance and maintenance are discussed in detail and the practical results of instrumentation recorded.—M. D. J. B.

Control of Sulphur in Steelmaking. G. Derge and S. Marshall. (Journal of Metals, 1951, vol. 3, July, pp. 511–516). This article summarizes the proceedings of the Sulphur Symposium, which was organized in February 1951 by the American Institute of Mining and Metallurgical Engineers, to consider the present-day trends in raw materials and the increasing importance of sulphur control. The subjects discussed were oxide–gas equilibria, activity of sulphur in liquid iron and steel, slag–metal reactions in the blast-furnace and the electric furnace, desulphurization of pig iron, and desulphurization in the open-hearth furnace. Brief summaries of each of the 15 papers presented are given.—G. F.

Application of Thermodynamics to Iron and Steel Making Processes. Sir Charles Goodeve and J. Pearson. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, May, pp. 329–335). Progress from the initial work of Le Chatelier is reviewed. The advantages of the use of free-energy diagrams and the concepts of chemical potential and capacity are discussed. The problems of desulphurization and dephosphorization in iron and steel making are considered in the light of these ideas.—A. G.

Studies in the Deoxidation of Iron—Deoxidation by Manganese. H. A. Sloman and E. Ll. Evans. (Journal of The Iron and Steel Institute, 1951, vol. 169, Oct., pp. 145–152). The preparation, analysis, and microscopical examination of a series of ingots, made by adding oxygen and manganese to 300–400 g. melts of pure iron, are described. The analyses reported include estimations of the total oxygen and manganese contents of the ingots, and chemical and X-ray analyses of the non-metallic inclusions obtained by alcoholic-iodine extraction. The product of deoxidation of iron by manganese is found to be the double oxide (Mn,Fe)O, the composition of which varies continuously with the metallic-manganese content of the alloy with which it is associated. The microscopical appearance of the inclusions in polished metal sections is described. The alcoholic-iodine method is shown to be unsatisfactory for the quantitative extraction of inclusions with a high MnO content. In the Appendix, a new calculation of the equilibrium conditions for deoxidation by manganese, using previously published data, is given. The experimentally determined composition of the double-oxide phase in an alloy of given manganese content is shown to be in reasonable agreement with that derived by calculation of the equilibrium at 1527° C. (1800° K.) between the alloy and a solid slag.

A Thermodynamic Study of the Reaction CaS + H_2 ⇌ CaO + H_2S and the Desulphurization of Liquid Metals with Lime. T. Rosenqvist. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, July, pp. 535–540; Journal of Metals, 1951, July). The author describes a study of the desulphurizing power of calcium oxide in its standard form of solid CaO. The reaction CaS (solid) + H_2O (gas) = CaO (solid) + H_2S (gas) is first considered thermodynamically in the temperature range 750–1425° C., the Gibbs free energy of the reaction being expressed as $\Delta F° = 15{,}650 - 0{\cdot}87\,T$. A study of the desulphurization of liquid copper with calcium oxide at 1200° C. is next described, the results indicating that the sulphur content of the copper is closely proportional to the ratio H_2O/H_2 in the atmosphere, the maximum solubility being about 1% at 1200° C. The application of the data to blast-furnace desulphurization is then considered, the general conclusion being that the sulphur capacity of a slag can be expressed as $a_{O^{2-}}/\gamma_{S^{2-}}$, where $a_{O^{2-}}$ is the activity of oxygen ions in the slag, and $\gamma_{S^{2-}}$ is the ratio of the activity of sulphur ions to percentage of sulphur in the slag. An experimental means of determining this quantity is given.—G. F.

Better Sulphur Elimination in Basic Open-Hearth Melting. J. G. Rivet. (American Foundryman, 1950, vol. 18, Dec., pp. 61–63). An investigation of a foundry basic open-hearth melting and slagging practice is reported, the object of which was to develop a procedure for the more efficient removal of sulphur. By the careful control of slag pH a sulphur content of less than 0·03% was obtained. It is desirable to aim at a pH of 11·4 which corresponds to a desulphurization ratio of about 7·3.—E. J. D. S.

The Reactions of Chromium towards Slags in the Basic Open-Hearth Furnace, with Reference to Chromium Recovery. P. Bremer. (Stahl und Eisen, 1951, vol. 71, May 24, pp. 575–580; June 7, pp. 605–611). The reactions of chromium with steel and slag have been followed during 33 heats in a basic open-hearth furnace. The conditions of importance for chromium yield from alloyed scrap, such as nature of charge, charging sequence, proportion of pig iron and lime used, sulphur, manganese, phosphorus, silicon, carbon, and chromium contents in the charge, and the influence of melting time, temperature, and nature of hearth are discussed. The partition of chromium between melting slag and metal in basic furnaces increased markedly with increasing FeO content, and decreased with increasing SiO_2 content, of the slag. This is similar to the behaviour of chromium under acid or silicate slags. It was also found that the value of K, *i.e.*, (Cr)[Fe]/(FeO)[Cr], had the same value in basic as in acid slags and that the chromium was present essentially in the divalent and not the trivalent form; the oxidized chromium does not form a compound with the lime. While the chromium content of the charge and the basicity of the slag have no effect on the behaviour of the chromium, the content of manganese and the basicity of the slag do play a part in the slagging of manganese. The conditions for good desulphurization are the same as those required for a high chromium yield and the opposite of those required for extensive dephosphorization. The influence of slag volume on chromium yield is discussed; it was established that the chromium content of the slag

Corrigenda

In the June *Journal*, p. 188, col. 1, the name of the author of 'Chile Now a Producer of Steel with Fully Integrated Plant' was omitted; it is F. Senior.

In the June *Journal*, p. 214, col. 2, 8th line from the end of abstract of Thum and Svenson's paper, for 'alternate' read 'lessen.'

In the August *Journal*, p. 439, col. 2, first abstract, the second author's name should read O. Carlsson.

plays a more important part than slag volume. The important chemical and physical conditions affecting carbon drop are dealt with. The suitability of chromium recovery for the production of high-quality heavy forging ingots and the economics of the process are discussed. There are important savings of ferrochromium.—J. P.

Jet Tapping of Open Hearth Furnaces. H. H. Northrup. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 83–86). The author describes how open-hearth furnaces are tapped with a 2-oz. explosive charge (*see* Journ. I. and S.I., 1951, vol. 169, Nov., p. 289). The jet tapper is now used on all heats tapped at the Buffalo, N.Y., and Warren, Ohio, plants of Republic Steel Corp.—M. D. J. B.

Electric Furnace or Open Hearth? C. F. Ramseyer. (Iron and Steel Engineer, 1951, vol. 28, June, pp. 57–67). The main features of a proposed modern top-charge electric furnace steel melting shop designed to produce carbon steels at low cost are developed in detail, and probable capital and operating costs estimated. Assuming the availability and use of purchased power, such a shop could be built at approximately half the cost of that of an open-hearth plant of equivalent capacity; with the present cost of power it could make steel from an all cold scrap charge more cheaply than the open hearth.—M. D. J. B.

Slag Materials and Action in Basic Arc Furnaces. C. B. Post and D. G. Schoffstall. (Journal of Metals, 1950, vol. 188, Nov., pp. 1313–1315: American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, 1950, vol. 8, pp. 18–29). The essential properties and action of basic electric arc furnace refining slags of the lime-fluorspar-silica type are discussed, and emphasis is placed on the use of slag-making materials.—G. F.

Investigation of New Special Deoxidisers. C. G. Mickelson. (Journal of Metals, 1950, vol. 188, Nov., pp. 1311–1311c; American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, 1950, vol. 8, pp. 148–159). The author summarizes the results of an investigation in which four special deoxidizing agents for cast steel were compared with the normal aluminium addition. These agents were: (1) Selenium, which in correct amounts improves the ductility of the steel, but which can only be used economically in special work owing to its high cost; (2) 'Graphidox,' an alloy containing 6% Ca, 50% Si, and 10% Ti, which puts the inclusions in a more harmless form and improves the physical properties; (3) an alloy containing 40% Si, 7–5% Mg, and 3–5% Al, which is found to be satisfactory in basic practice, where lower residual silicon contents are obtained; and (4) sodium, in both metallic form and as an emulsion in kerosene, which is a powerful deoxidizing agent.—G. F.

Alloy Steel Production in Large Basic Furnaces. A. K. Blough. (Journal of Metals, 1951, vol. 191, Jan., pp. 30–32); American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, 1950, vol. 8, pp. 104–111). The author describes the production of alloy steels in 60-ton basic electric arc furnaces at the Republic Steel Corporation, Canton, Ohio.—G. F.

Stainless by Induction Melting. R. J. Wilcox. (Journal of Metals, 1950, vol. 188, Nov., pp. 1311D–1312). **Induction Melting of Stainless Steels.** R. J. Wilcox. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, 1950, vol. 8, pp. 115–119). A brief description is given of the induction melting practice used at the Michigan Steel Casting Co., Detroit, for the production of stainless and heat-resisting steels. Special reference is made to degasification of the melt by an addition of ¼ lb. of 50% ferroselenium per ton of steel, which is extremely effective in eliminating gas porosity.—G. F.

Melting in High-Frequency Furnaces. F. Linnhoff. (Elektrowärme Technik, 1950, vol. 1, No. 5–6, pp. 128–131). A survey of the development of high-frequency furnaces is given, with particular reference to the design of modern furnaces of up to 12 tons capacity and an output of 3000 kW. employed for melting steel. Problems relating to furnace linings are discussed.—P. F.

A Few Fundamental Considerations Concerning the Application of Graphite Rods as Electric Heating Elements. O. Junker. (Elektrowärme Technik, 1951, vol. 2, No. 1, pp. 5–10). Calculations and data relating to the design of a 300-kg. graphite-rod resistance furnace for melting steel, with special reference to the electrical properties of the graphite rod are presented.—P. F.

Continuous Casting of Steel at Babcock & Wilcox Tube Co. I. Harter, jun. (Journal of Metals, 1951, vol. 3, Mar., pp. 223–226; American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Proceedings, 1950, vol. 8, pp. 31–45; Association of Iron and Steel Engineers, Yearly Proceedings, 1950, pp. 765–700). *See* Journ. I. and S.I., 1951, vol. 168, June, p. 189.

Some Observations on the Continuous Casting of Steel. (Journal of Metals, 1951, vol. 3, Mar., pp. 227–228). This article describes the continuous casting machine built by Continuous Metalcast Corp. and gives details of the operation of these machines on a pilot plant basis at the Watervliet works of Allegheny Ludlum Steel Corp. The differences in the plant and practices at this works and at the Babcock and Wilcox Tube Co. works are pointed out. The adaptability of continuous casting to steel production is discussed.—G. F.

Steel Composition and Ingot Cracks. G. R. Bashforth. (British Steelmaker, 1951, vol. 17, Apr., pp. 198–202). The author discusses the types of ingot cracks associated with different types of steel, dealing particularly with the clinking of high-carbon steel ingots and the hair-line cracks associated with certain alloy steels. He then discusses the adverse effect of residual elements on the rolling properties of the steel, the phenomenon of the peritectic change, and cracking caused by sulphur both in the ingot stage and during subsequent cogging. Finally, the more important production controls which should be adopted to avoid these defects are discussed.—G. F.

PRODUCTION OF FERRO-ALLOYS

The Basis of the Electrothermal Extraction of Ferrotungsten. H. Härter. (Zeitschrift für Erzbergbau und Metallhüttenwesen, 1950, vol. 3, Oct., pp. 325–328). The author describes the occurrence and treatment of tungsten-bearing ores and discusses in some detail the process for making ferrotungsten practised at a German works before 1939.—O. H. G.

Disintegration of 45–50% Ferro-Silicon and the Generation of Poisonous Gases. A. K. Prestrud. (Journal of The Iron and Steel Institute, 1951, vol. 169, Oct., pp. 107–109). A war-time experiment with ferrosilicon showed an uneven distribution of the different elements in the cast. The analytical figures are compared with data from the iron–silicon equilibrium diagram. The influence of aluminium on the disintegration of certain grades of ferrosilicon with the evolution of phosphine is discussed, and the cause of disintegration is suggested.

Electrothermics and Electrothermal Processes. C. H. Aall. (Castner Memorial Lecture; Chemistry and Industry, 1950, Dec. 30, pp. 830–840). The electric furnace is described as one in which the current is used for heating purposes only, and the reaction is always a reduction process. The author traces its historical development, including the reasons for the exclusive use of alternating current nowadays (generally three-phase with larger furnaces) in order not to upset the balance in the power supply. The power factor is critical. The arrangement of the three electrodes in line or in a triangle is discussed, the former method requiring special techniques to distribute the power load equally. The invention of the continuous Söderberg carbon electrode, which is steel-encased and self-baking, is described. A roof for the crucible is desirable, but very difficult in the case of pig-iron and ferro-alloy furnaces. Rotation of the crucible helps to prevent caking on the electrodes, but it is usually still necessary to poke it, often by hand. Tapping is sometimes done by a small electrode. The manufacture of calcium carbide and cyanamide are dealt with. Production of ferro-alloys is then outlined, here silica is reduced by coke and dissolves in iron, and if a low-silicon steel is required the silicon may then be removed using basic slag. If high-grade ferrosilicon is being produced, efficiency decreases, as more silicon enters the vapour phase in equilibrium with the alloy. Power consumption varies from 5000 kWh./ton for 50% ferrosilicon to 15,000 or more for a 95% silicon alloy. The manufacture of electric pig iron is described.—N. McE.

More Manganese from American Ores and Slags. E. C. Wright. (Metal Progress, 1951, vol. 59, Mar., pp. 347–353). In steelmaking some manganese is wasted by solution in slag.

The paper outlines a method of concentrating this waste manganese, by smelting the slags in a blast-furnace to produce high-manganese pig iron, which is then partially oxidized in a converter to give a high-manganese slag. This improved slag has a ratio of MnO to FeO greater than four, and it can therefore be used for producing ferromanganese alloys. Evidence is given of the feasibility of this plan.—E. T. L.

FOUNDRY PRACTICE

Russian Technical Achievements in Foundry Industry. Z. Lenartowicz. (Przeglad Odlewnictwa, 1951, vol. 1, Feb., pp. 34–38). [In Polish]. After a short review of the present problems of the Russian foundry industry, the author surveys the results already achieved.—V. G.

Production of Castings for Subsequent Vitreous Enamelling. W. Todd. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1951, vol. 91, July 5, pp. 18–20). Castings for enamelling should be of uniform thickness, of even section, free from pinholes and surface defects. A fine-grained structure, with no cementite is also desirable.—J. E. W.

Cost Estimation for Iron Casting. C. G. Nilsson. (Gjuteriet, 1951, vol. 41, Feb., pp. 19–22). [In Swedish]. The author analyses casting costs and presents graphs for assessing them—R. A. R.

Statistical Quality Control Manages Foundry Operations. R. J. Feltrin. (American Foundryman, 1951, vol. 19, Jan., pp. 40–42). The paper describes how a modified statistical quality control system was used as a means of managing metallurgical operations in a Canadian foundry. There are ten references.—E. J. D. S.

Norwegian Foundrymen Look at America's Ferrous Foundries. J. L. Sissener. (American Foundryman, 1951, vol. 19, Feb., pp. 56–58). The impressions of the leader of a Norwegian foundry productivity team, after visiting 18 American ferrous foundries are reported.—E. J. D. S.

Ferrous Casting in Australia. (American Foundryman, 1951, vol. 19, Jan., pp. 32–35). This paper reviews iron and steel foundry practice in Australia.—E. J. D. S.

Foundry Management To-day. J. Stott. (Foundry Trade Journal, 1951, vol. 90, Apr. 26, pp. 435–445). The average foundry unit is of small size and management techniques must suit small units. Main improvements that are possible without the full use of production study include attention to yield control, and the setting up of production standards, thus enabling production control to be achieved. Production control standards having been attained will enable cost control to be established. Improvements in the handling of materials and a system of management training for junior employees are advocated, and possible methods of improving plant tidiness are enumerated.—J. E. W.

Foundry Education. A Report of the Foundry Education Foundation. G. K. Dreher. (American Foundryman, 1951, vol. 19, Jan., pp. 56–58). The past accomplishments, future plans, response to foundry training facilities, and the scope of foundry schools in technical colleges and universities in America are reviewed.—E. J. D. S.

Thermal Considerations in Foundrywork. V. Paschkis. (Institute of British Foundrymen, 1951, Preprint No. 995; Foundry Trade Journal, 1951, vol. 91, June 21, pp. 661–667; June 28, pp. 699–704, 708). Melting furnaces, ladles, the process of casting, and mould and core drying are items to which a study of the thermal problems involved, would prove advantageous. Methods of making these studies are reviewed. The analogue computer has proved successful in studying these problems, and its advantages and details of the techniques employed are enumerated. The analyser has been used to check the work of Clark, and of Briggs and Gezelius on the solidification rates of slabs and spheres, and has enabled work to be done on the influence of variations in the heat conductivity of the sand, and of the influence of moisture on the conductivity of sand. Chworinoff's statements that bodies having the same shape factor solidify in the same time, irrespective of their size and individual shape, and that solidification times vary proportionally to the square of the shape factor are examined.—J. E. W.

Cupola Linings. E. O. Lissell. (Gjuteriet, 1951, vol. 41, Mar., pp. 35–43). [In Swedish]. Wear and attack on linings by the charge are discussed with reference to charge composition and mode of attack. Composition and properties of lining and patching materials are given together with recommendations for reducing burn-out.—B. S. E.

Cupola Drop Bottoms. J. Timbrell. (Foundry Trade Journal, 1951, vol. 90, May 10, pp. 501–502). A means of minimizing the dangers attendant upon the dropping of cupola bottom doors at the end of a blow, is given. Factors influencing the speed of the drop are examined; the well should be tapered towards the shell, at the junction of the rammed bottom and the side walls.—J. E. W.

Installs Modern Cupola Charging Equipment. (Foundry, 1951, vol. 79, Mar., pp. 136, 138). A modern scrap handling and cupola charging installation is described.—E. J. D. S.

Preheating the Hearth of a Cupola. S. Pelczarski. (Przeglad Odlewnictwa, 1951, vol. 1, Mar., pp. 84–87). [In Polish]. The iron from the first two or three tappings from a cupola often runs cold, and cannot be used for complicated castings. This can be prevented by the introduction of blow holes near the bottom of the cupola, thus obtaining good preheating of the hearth with burning coke and combustion gases. After preheating the blowholes are closed with moulding sand. A diagram and the method of blowing in a modified cupola are given.—V. G.

Cupola Melting in the Husquarna Foundries. G. Lindgren. (Gjuteriet, 1951, vol. 41, Jan., pp. 1–9). [In Swedish]. Cupola practice in two Swedish foundries is described with reference to materials handling, blast control, and control measures for raw materials.—B. S. E.

Efficient Operation Doubles Foundry Production. R. H. Herrmann. (Foundry, 1951, vol. 79, Mar., pp. 90–95, 240–242). A review is given of the lay-out and operations employed at the Massey-Harris mechanized foundry.—E. J. D. S.

Selection and Use of Anthracite for Cupola Fuel. C. C. Wright. (Foundry, 1951, vol. 79, Mar., pp. 96–97, 210–211). Recommendations are made for the substitution of anthracite for coke in cupola practice.—E. J. D. S.

Costs *vs.* Benefits of Oxygen-Enriched Cupola Melts. F. Carl. (American Foundryman, 1951, vol. 19, Feb., pp. 28–29). Performance data in the literature relating to 19, 48, and 72-in. cupolas operated with oxygen-enriched blast are summarized. There is general agreement that the cupolas were less liable to bridging, had cleaner melts and less slag at the tuyeres. However, the author concluded that, despite certain advantages, the storage facilities, generating units, and unit costs must be given further study before oxygen-enriched blast can be generally applied to cupolas.—E. J. D. S.

Basic Lined Cupola Permits Use of Lower Grade Scrap and Coke. S. F. Carter. (American Foundryman, 1951, vol. 19, Jan., pp. 50–51). A summary of the results of experimental heats in a pair of 23-in. cupolas, one acid and one lined with dead burned magnesite brick, and a 36-in. production cupola, is given. The advantages of using a basic lining are discussed in relation to the removal of sulphur and phosphorus. The most promising use of the basic cupola seems to be for making nodular iron.—E. J. D. S.

Improved Methods of Desulphurizing Iron. J. Tucholka. (Przeglad Odlewnictwa, 1951, vol. 1, Mar., pp. 79–84). [In Polish]. The desulphurization of molten iron in ladles by the soda-ash method, the influence of ladle lining and the chemistry of the process are discussed.—V. G.

Standard Structure for Graphite Formation in Grey Cast Iron. C. W. Pfannenschmidt. (Giesserei, 1951, vol. 38, July 26, pp. 355–359). Following the American example, the Grey Cast Iron Committee of the Verein Deutscher Giessereifachleute is trying to introduce a standard classification of graphitic structures in grey cast iron. Thirteen micrographs with associated standard line diagrams are reproduced and briefly described.—J. G. W.

Instruments Keep Accurate Records. M. F. Degley. (Foundry, 1951, vol. 79, Mar., pp. 108–111). Applications and advantages of instrumentation in foundry cupola, sand plant, and core stove operations are discussed.—E. J. D. S.

High-Silicon Cast Iron. C. Kalata and Z. Tyszko. (Przeglad Odlewnictwa, 1951, vol. 1, Jan., pp. 11–19). [In Polish]. An outline of the history of the discovery and production of high-silicon cast iron is given. Its chemical composition, rôle of individual components, and chemical, mechanical, and casting properties are described. Methods of preparing molten metal and moulds are outlined and the principles of the construction of castings from high-silicon iron are discussed.—V. G.

The Technology of Modified Cast Iron and the Possibilities of Its Production in Poland. G. Kniaginin. (Przeglad Odlewnictwa, 1951, vol. 1, Feb., pp. 38–42 ; Mar., pp. 77–79). [In Polish]. A short description of necessary equipment, methods of production, and heat-treatment of modified cast iron is given and the possibilities of its production in Poland are discussed.—V. G.

Notes on the Mechanism of Graphitization in Nodular Cast Iron. J. M. Navarro Alvargonzalez. (Instituto del Hierro y del Acero, 1951, vol. 4, Apr.–June, pp. 143–146). [In Spanish]. A series of micrographs is presented, showing various sections of nodular cast iron (C 3·03, Si 2·16, P 0·006, Mn 0·4%). Nodular graphite appears to have the same origin as the graphite in black-heart malleable iron.—R. S.

Eliminate Second Inoculation in New Nodular Iron Process. A. L. DeSy. (American Foundryman, 1951, vol. 19, Feb., pp. 41–45). In order to make a magnesium-treated low-sulphur iron grey as well as nodular a second inoculation treatment is necessary. A number of experiments using calcium alloys is reported in which nodular grey iron was produced without the double treatment. The results showed varying degrees of success, the alloys used being Cu–Ca, Cu–Ca–Si, Cu–Ca–Si–Ni, Ca–Si, combinations of Ca–Si–Mg–Cu–Ni, Ca–Mg–Li, and alloys containing various proportions of Cu, Si, Li, Cu, and Ni. The experiments were of a preliminary nature but the results show that a nodular grey iron may be produced satisfactorily by a single alloy addition, except for very thin sections—E. J. D. S.

Nodular Iron—A Bibliography. F. R. Morral. (American Foundryman, 1951, vol. 19, Jan., pp. 43–44). This contains 109 references to the literature and patents.—R. A. R.

Notes on Cast Iron—Past and Present. E. Longden. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, May 10, pp. 487–496 ; May 17, pp. 521–526). Methods for the production and heat-treatment of nodular iron are outlined. The general heat-treatment of cast iron is referred to and the heat-treatment temperature ranges for grey cast iron, malleable iron and steel are compared. A review is then given of special process cast irons, those referred to being Lang (hot mould) iron, Emmel iron (cold mould), Schuz iron (mould chilled), low carbon cast iron, Meehanite iron, and Ni-Tensyl iron. Cupola practice as the usual method of melting cast iron, is then considered, with special reference to the mixing and rotation of charges and the calculation of the mixtures. Finally, an extensive list is given showing recommended analyses for various classes of castings.—J. E. W.

Cast-Iron Test Bars. S. Pelczarski. (Przeglad Odlewnictwa, 1951, vol. 1, Jan., pp. 8–11). [In Polish]. The correct methods of taking control samples for strength tests are given. The differences between test bars cast separately and as part of the casting, and the effect of position of specimen in the latter case, are discussed.—V. G.

Iron for Ingot Moulds. F. Bongarçon. (Documentation Métallurgique, 1950, July–Sept., pp. 103–106). The combined carbon content fixes the value of a hematite iron for ingot moulds. Use of pure hematite permits a combined carbon content of 0·350% to be obtained. If pure hematite is used in a furnace contaminated by lead-bearing ores, bad results are obtained. The influence of the amount of scrap used in melting ingot-mould iron is not well understood and merits further study.—R. S.

Side-Blown Converter Practice in Russian Steel Foundries. W. Kuczewski. (Przeglad Odlewnictwa, 1951, vol. 1, Apr., pp. 94–98). [In Polish]. Side-blown converter practice is described. The main characteristics are : (1) Processing of iron, well carburized and low in silicon, obtained by melting low-phosphorus iron with steel scrap in the cupola, giving a phosphorus content of about 0·05–0·06% ; (2) process time 7–10 min. ; (3) high final temperature ; (4) good quality of steel made due to low FeO content ; and (5) about 10% of the sulphur is removed with gases and about 23% with slag.—V. G.

Homogenization of Cast Steels. M. T. Aktutay and P. C. Rosenthal. (Foundry, 1951, vol. 79, Mar., pp. 100–105, 242–244). The tensile properties and microstructures of homogenized experimental steel castings are presented. The effectiveness of homogenization may be critically related to the carbon content. The most important changes in properties occurred in 0·40% carbon alloy steel, test castings. Although the routine treatment of ordinary castings is probably not justifiable, it may be justifiable for castings of heavy section, in which maximum physical properties and a good hardenability are required.—E. J. D. S.

Foundry Sand—Getting Down to Fundamentals. C. E. Wenninger. (American Foundryman, 1951, vol. 19, Jan., pp. 45–48). The author argues that the empirical treatment of foundry sand problems and control methods leads sometimes to a confusion of ideas. For example, it may be said that excess moisture causes scales, but it is not true that all scabs result from excess moisture.—E. J. D. S.

Example of Mechanized Equipment for Preparing Moulding Sand. S. Werner. (Przeglad Odlewnictwa, 1951, vol. 1, May, pp. 122–128). [In Polish]. The mechanization of the preparation of moulding sand and its economic advantages are discussed.—V. G.

Synthetic Resins in the Foundry. (Institute of British Foundrymen, Paper No. 998 : Foundry Trade Journal, 1951, vol. 91, July 5, pp. 3–9). As a result of a questionnaire circulated to foundries, information given by the British Plastics Federation and the sub-committee's members' experience, the technical, economic and health aspects of urea-formaldehyde and phenol-formaldehyde bonded sands in the production of cores is discussed in detail.—J. E. W.

Clay as a Bond in Moulding Sands. M. Stap. (Centraal Instituut voor Materiaal Onderzoek, 1950, Circular 9, Apr., pp. 2–7). [In Dutch]. Since the plasticity and strength of moulding sand depend on the bonding, the constitution and nature of clay are examined. Relationships between density, plasticity, green strength, and moisture content are discussed.

Research on Core Binders. O. Kulma and Z. Wertz. (Przeglad Odlewnictwa, 1951, vol. 1, May, pp. 128–134). [In Polish]. Methods of testing core binders are described and results of the investigation of binders are given.—V. G.

Core Sag Controlled. T. Barlow. (American Foundryman, 1950, vol. 18, Dec., pp. 57–60). The improvement of core-sand properties by additions of southern bentonite is demonstrated.—E. J. D. S.

Gray Iron Shrinkage Related to Molding Sand Conditions. C. A. Sanders and C. C. Sigerfoos. (American Foundryman, 1951, vol. 19, Feb., pp. 49–55). An investigation of the effects of sand and casting conditions on the shrinkage of castings is reported. The following variables were studied : (1) Bond additions ; (2) rammed density of sand ; (3) pouring temperature ; (4) pouring rate ; (5) sea coal additions ; (6) moisture content ; (7) oil sand moulds ; and (8) special ceramic materials, such as zircon flour. Variations in mould materials will influence metal solidification, and as carbonaceous materials are gradually increased the piping in the riser decreases. Oil bonded core sand produced sound castings. All heats were of grey iron and the pouring temperature was about 2600° F.—E. J. D. S.

Mold Materials Are Factors in Gray Iron Shrinkage. W. F. Bohm. (American Foundryman, 1951, vol. 19, Jan., pp. 26–29). The shrinkage cavity forming the subject of this paper was characterized by : (1) A fairly smooth surface with no dendrites ; (2) its location in a comparatively heavy section on the upper cope surface, but sometimes it was below at a hot spot slow to solidify ; and (3) the presence of ' beads ' of eutectic. Experiments on cylindrical test castings showed that this type of defect was associated with a change in casting dimensions and the composition and properties of the moulding materials. The beneficial results of the sea coal and southern bentonite additions to the moulding material were demonstrated.—E. J. D. S.

Testing of Sand under Impact. W. H. Moore. (American Foundrymen's Society, 1951, Preprint No. 30 : Australian Foundry Trade Journal, 1951, vol. 2, June, pp. 5–6). The value of the deformation test, either alone or together with green strength is discussed and its limitations stated. To provide a new measure of toughness, or the product of deformation and green strength, a modified Izod impact test was devised. The point of maximum toughness is coincident with the point of maximum impact strength. A pilot apparatus to determine hot impact values is described.—P. C. P.

Modern Core Sand Practice. R. H. Greenlee. (American Foundrymen's Society, 1951, Preprint No. 59). This paper deals mainly with the application of thermosetting resins as core sand binders. One advantage is the shorter drying time possible, using either a core stove or dielectric heating. Extremely hard surfaces can be produced after curing due to the migration of the resin towards the surface of the core. The moisture content appears to be more critical than with

core oils, and resin cores usually have a higher moisture content. Thermosetting resins impart a stickiness to core sands and impair workability. Materials added to overcome this are the lighter oils—P. C. P.

Effect of Sand Grain Distribution on Casting Finish. H. H. Fairfield and J. MacConachie. (American Foundrymen's Society, 1951, Preprint No. 24). Six different types of sand grain distribution patterns were produced by blending screened silica sands. Bronze test castings were cast in these sands. A precision laboratory moulding machine was used. Moulds were made with different degrees of ramming and the surface smoothness of the castings was measured. The conclusions were : (1) The sand with the lowest permeability and highest grain fineness produced the best finish ; and (2) peaked or normal grain distribution did not have the best flowability. A sand with a non-symmetrical, broad distribution had the best flowability.—P. C. P.

Heat Flow in Moist Sand. V. Paschkiss. (American Feundrymen's Society, 1951, Preprint Ne. 3). This paper describes the extension of work using the ' Heat and Mass Flow Analyser ' to the problem of heat flow in moist sand. The way in which heat flow occurs and the values to give to thermal conductivity, specific heat, and diffusivity are discussed. The moisture content exerts a stronger chilling action if the pouring temperature is lower, and in all cases the chilling action is only of brief duration.—P. C. P.

Some Present-Day Practices in Patternmaking. B. Levy. (Institute of British Foundrymen, 1951, Preprint No. 999 : Foundry Trade Journal, 1951, vol. 91, July 19, pp. 57–64). After briefly recalling the factors governing the choice of pattern required, the various types of pattern available are enumerated, and their particular uses outlined. Among the different types mentioned are : (1) Strickleboards ; (2) skeleton patterns ; (3) semi-permanent patterns in softwood ; (4) hardwood patterns ; (5) hardwood reinforced with sheet or metal castings ; (6) pressure-cast aluminium and (7) part or wholly machined metal patterns. The types of machine required for the manufacture of metal patterns are described, and the production of plastic patterns is outlined.—J. E. W.

Chemical Chilling and Feeding. J. E. R. Tompkin. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 91, July 5, pp. 11–13, 16). The use of tellurium in place of metallic chills is described with examples. The best method of promoting feeding is with exothermic feeding compounds applied to the various feeder heads—J. E. W.

Some Notes about Risers. P. Januszewicz. (Przeglad Odlewnictwa, 1951, vol. 1, Jan., pp. 6–8). [In Polish]. A short discussion of the correct use of risers with regard to their position and dimensions is given.—V. G.

Choke Control in Finger Gating. W. H. Johnson, H. F. Bishop, and W. S. Pellini. (Foundry, 1951, vol. 79, Apr., pp. 116–121, 275–278). Designs of finger gating systems were studied to evolve general principles of choke control for multiple finger gating systems. In a free or unchoked system the metal follows preferential paths dictated by the inertia of the metal stream and the design of the gating system, resulting in non-uniform flow. If chokes occur at the finger inlets, pressure rises in the gating system and uniform flow occurs from all fingers.—E. J. D. S.

Electronic Core Baking. B. Hopkins. (Foundry, 1951, vol. 79, Mar., pp. 154, 212). The economic advantages obtained with the use of high-frequency current core-baking equipment are detailed. Core-room yield was greatly increased, whilst 240 typical cores of various sizes and shapes were baked in 40 min.—E. J. D. S.

Core Practice as Related to Malleable Foundry Losses. E. J. Jory. (American Foundryman, 1951, vol. 19, Mar., pp. 44–47). Core defects which can be directly or partly responsible for common faults in castings are analysed and recommendations to improve core-making practice are offered. Hot tears caused by bad cores may be obviated by the careful control of core weight and if tears persist a sand filler may be used. However, although sawdust up to 25% by volume is an effective remedy, this material has several disadvantages and it should not be used until other methods of preventing hot tears have been tried. The causes of scabs, core blows, metal penetration, dimensional variations in castings, shrinks, misruns, and cold shuts are also examined, and steps to remove the causes are suggested.—E. J. D. S.

Loam and Dry-Sand Moulding for a Crane Barrel. T. Walton. (Institute of British Foundrymen : Foundry Trade Journal 1951, vol. 90, June 7, pp. 611–613). The moulding by a combined dry-sand and loam-moulding method of a hollow crane-barrel casting 3 ft. outside dia. and 11 ft. long is described.—J. E. W.

Manufacture of Propellers and Other Castings. C. W. Stewart. (Institute of British Foundrymen, June, 1951, Paper No. 1002 : Foundry Trade Journal, 1951, vol. 91, Sept. 13, pp. 301–308). The moulding and patternmaking problems in making propellers up to 22½ tons, gear wheel centres up to 30 tons, and low, medium, and high-pressure cylinders, are described. The small size of the foundry calls for careful planning and correlation of moulding and coremaking processes.—J. E. W.

Production of Heavy Castings for Electrical Generating Equipment. N. Charlton. (Institute of British Foundrymen, June, 1951, Paper No. 1001). The production by loam moulding methods of castings such as low-pressure cylinder and exhaust sections, which weigh up to 26 tons, at the foundry of C. A. Parsons and Co., Ltd., is described. Features include the use of a sandslinger, for backing up the loam facing with sand ; the use of a cast block to fill the centre portion of the core assembly, in order to facilitate easing of the cores after casting, and the employment of their patented silicon carbide blocks as denseners where necessary. Reference is made to the moulding methods employed for the production of smaller castings by box moulding, and the sand handling equipment is briefly described.—J. E. W.

Loam Moulding of Pump Casings and Impellers. E. Clipson. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, May 17, pp. 515–520 ; May 24, pp. 547, 551). The production by loam moulding methods of a volute section of a 102-in. centrifugal pump and of a turbine impeller of the double entry, shrouded-pattern type is detailed. Owing to the small floor space available at Foster Gwynnes Foundry, Lincoln, attention had to be given to planning, having regard to stoving facilities and lifting capacity of cranes. Attention was drawn to the high contraction of nickel irons, and in the discussion the use of hemp instead of straw ropes was revealed, as these burnt out during the drying operation.—J. E. W.

Suffolk Iron Foundry. A. R. Parkes (Foundry Trade Journal, 1951, vol. 90, May 3, pp. 463–472). This foundry, now owned by H. Kaufmann Ltd., consists of a mechanized iron foundry, a die-casting shop, fettling, core and patternshops, a machine shop, a woodworking section, and finishing departments. A description is given of the layout and equipment of the foundry which make possible the production of 90,000 castings a week.—J. E. W.

Jobbing Founding on Scientific Lines. (Foundry Trade Journal, 1950, vol. 89, Nov. 16, pp. 383–386, 398). A brief account is given of the activities at the foundry of J. Hobkirk, Sons and Co., Bedford, where castings complying with difficult specifications are made. The iron foundry has two cupolas which run on alternate days and have a nominal capacity of 2 tons/hr.—R. A. R.

Valve Tappet Castings. R. Dulché. (Institute of British Foundrymen : Foundry Trade Journal, 1951, vol. 90, June 7, pp. 597–605). After describing the equipment required for the production of 25,000 tappets per month the method of producing these castings within the required limits of hardness and depth of chill is detailed. The cupola melted metal contains C 2·9–3·1 (total), Mn 0·8–1·0, Si 2·0–2·2, P $< 0·1$ and S $< 0·06$%, and it must be poured at a temperature between 1340° and 1380° C. After describing the fettling and inspection procedure, a short account is given of the foundry layout and organization for the production of these castings at a French foundry.—J. E. W.

Gradual Mechanization of Small Foundries. J. Mojmir. (Przeglad Odlewnictwa, 1951, vol. 1, Feb., pp. 53–57). [In Polish]. The mechanization in three stages of a small iron foundry is described.—V. G.

Further Mechanical Aids for the Foundry. A. S. Beech. (Institution of Mechanical Engineers, Mar. 9, 1951, Advance Copy). New mechanical and semi-mechanical devices put into practice in the foundry between 1942 and 1949 are described. They include in the mass-production shop, the moulding machine, brake block production equipment, a modern knocking-out station, plant for sand preparation and reconditioning and a multiple-belt storage hopper. Jobbing foundry equipment is also discussed.—R. A. R.

Casting Defects and Their Causes. Part I. J. Drachmann.

(Gjuteriet, 1951, vol. 41, Apr., pp. 51–57). [In Swedish]. Casting defects are classified into 12 main groups with subdivisions. Illustrations of the commonest types of defect with the Swedish terminology are given, and an analysis of the fundamental causes of defects is attempted.—B. S. E.

What to do About Air Pollution. J. M. Kane. (American Foundryman, 1951, vol. 19, Feb., pp. 34–38). A brief, general discussion of dust and fume control for various foundry operations, and of air pollution regulations is presented. Except for melting and pouring, dust control in the foundry is not a serious problem.—E. J. D. S.

Principles of Rate Fixing in Foundries. M. Skarbinski. (Przeglad Odlewnictwa, 1951, vol. 1, Mar., pp. 64–77). [In Polish].

HEATING FURNACES AND SOAKING PITS

Experiments in Ferrous Metallurgy with a Solar Furnace. F. Trombe and M. Foëx. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, May, pp. 353–358). A parabolic mirror, 2 m. in dia., of 85 cm. focal length melted iron directly at a rate of 1·5–2 kg./hr. and in a 300 c.c. furnace at 1·2 kg./hr. The furnace has a good efficiency in comparison with various electric furnaces.—A. G.

Metallic Recuperators for Slab Heating Furnaces. R. R. Shedd. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 55–62). A description is given of eight new continuous slab heating furnaces built for the United States Steel Co. Five are triple-zone, continuous furnaces each with a nominal rating of 105 gross tons/hr. The three other furnaces are rated at 65 gross tons per furnace hour. Metallic tube recuperators are installed for which the following advantages are claimed : (1) Close operating control of temperature and pressure, permitting satisfactory utilization of fully automatic instrumentation and control on a slab heating furnace ; (2) economical recovery of heat from flue gases and increased efficiency of heating ; and (3) low maintenance costs. Fuel consumption is believed to be lower than with furnaces employing other recuperators.—M. D. J. B.

Regenerative Furnaces and Silicon Carbide Tubes. (Tecnica e Industria, 1951, vol. 29, May, pp. 399–400). [In Spanish]. The characteristics and advantages of silicon carbide tubes as used in reheating furnaces are described.—R. S.

Preventing Fuel Explosions in Gas and Oil Fired Industrial Furnaces. J. B. Smith. (Industrial Heating, 1950, vol. 17, Oct., pp. 1729–1734, 1840, 1844 ; Nov., pp. 1950–1954, 1964). Procedures for reducing the risk of explosions in industrial gas and oil fired furnaces are given. It is pointed out that the most important factors are : (1) Selection of well-trained 'burner men' to 'light-off,' adjust burner mixers, fan blowers, temperature and safety controls, and to 'shut down'; (2) establishment and execution of a periodic testing and maintenance programme.—J. A. L.

Oil Firing of Heating and Melting Furnaces. K. Guthmann. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 441–449). Experiences with oil firing abroad as revealed by the technical literature are reviewed and examples of application to reheating and open-hearth furnaces given. The addition of supplementary oil firing to some West German cold-gas open-hearth furnaces is described.—J. P.

Evolution in the Construction of Electric Furnaces. F. Barbas. (Métaux et Industries, 1950, No. 1, pp. 24–32). The desirability of improving the gas-tightness of electric resistance furnaces is discussed, and a method of sealing furnace doors is described. The advantages and the field of application of sealed furnaces are outlined.—T. E. D.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Principles of Heat-Treatment of Steels. L. Dainelli. (Rivista di Meccanica, 1951, vol. 2, Apr. 10, pp. 19–24 ; Apr. 25, pp. 13–18). [In Italian.] The author gives a concise and clear picture of the fundamentals of heat-treatment of steels. The structural behaviour of steels, transformations, **S**-curves, tempering, annealing, normalizing, and cementation are considered. The properties of steels submitted to these treatments and the methods of carrying them out are described.—M. D. J. B.

Modern Heat-Treatment. A. Michel. (Documentation Métallurgique, 1950, Jan.–Mar., pp. 3–22). Earlier studies of the isothermal transformation of austenite are reviewed and the more recent methods of isothermal annealing, martempering, austempering and sub-zero treatment are described. Hardening and surface stressing and the stabilization of austenite by ageing are discussed, their practical applications being indicated.—R. S.

Some Aspects of the Problem of Artificial Atmosphere in Electric Heat-Treating Furnaces. J. J. M. Roos. (Belgian-Dutch Congress on Electric Heating and Electrochemistry : Metalen, 1951, vol. 6, June 15, pp. 215–216). [In Dutch]. The paper discusses types of furnace atmospheres and methods of producing them. Decarburization of transformer sheets and the manufacture of malleable iron are dealt with as examples of the loss of elements due to heat-treating. Carburizing and nitriding are discussed.—R. S.

Gas Carburising of Steel with a Butane-Town Gas Mixture. D. W. Bloor. (Iron and Coal Trades Review, 1951, vol. 163, July 13, pp. 85–86, 84). The author briefly discusses the fundamentals of gas carburizing and then describes the use of a butane/town-gas mixture as a carburizing gas. Factors affecting the rate of carburizing and the quality and depth of the case are considered ; finally, the detrimental effects of hyper-eutectoid cementite in the case are discussed.—G. F.

Good Carburizing Practice. T. A. Frischman. (Machinist, 1950, vol. 94, Nov. 11, pp. 1615–1619 ; Nov. 18, pp. 1666–1670 ; 1951, vol. 95, Jan. 6, pp. 18–21 ; Jan. 13, pp. 52–55 ; Jan. 20, pp. 83–87 ; Feb. 17, pp. 227–230 ; Mar. 3, pp. 314–317; Mar., 17, pp. 386–389 ; Apr. 14, pp. 538–541 ; Apr. 28, pp. 619–622 ; May 12, pp. 692–695 ; May 19, pp. 734–736). Part I of this series of articles deals with the charcoal and coke types of packing material and methods of reducing the distortion of carburizing pots and boxes. Part II covers the advantages and disadvantages of pack carburizing and shows why gas carburizing is coming more to the fore. Part III describes the production of carburizing and carrier gases and Part IV describes the control of the gaseous process. Part V points out the fast heating and other advantages of the salt-bath process. Part VI gives the compositions of several carburizing steels. Part VII explains how to select the case depth and refine the case. Part VIII deals with the control of distortion and Part IX with selective carburizing. Part X explains how the alloying elements in the steel affect the carbon concentration at the surface and the hardness. Part XI outlines methods for determining hardenability and describes devices for controlling the dewpoint of gases. Part XII discusses the measurement of case depth and hardness.—R. A. R.

Heat-Treatment of Gears and Bands for Buick Dynaflow Transmission. H. A. Maloney. (Industrial Heating, 1950, vol. 17, Oct., pp. 1694–1704). In this report, details of the transmission gearing of the Dynaflow transmission are given. Its special characteristics demand particular methods of heat-treatment, and these are described.—J. A. L.

Cooling Rates in Modern Furnaces. M. H. Mawhinney. (Industrial Heating, 1950, vol. 17, Oct., pp. 1708–1714). The author presents methods by which the cooling rates of furnaces under different conditions may be estimated. After listing the principal factors involved the author deals first with batch and then with continuous furnaces.—J. A. L.

Hardening and Heat-Treating in the Salt Bath. C. Albrecht and E. Zeitz. (Elecktrowärme Technik, 1950, vol. 1, No. 5–6, pp. 136–138). A survey of the development of electrically heated salt-bath furnaces employed for the heat-treatment of steel is given. The advantages of the salt-bath over other methods are discussed.—P. F.

Heat-Treatment and Bright Annealing of Steel. K. Tamele, (Elektrowärme Technik, 1950, vol. 1, No. 5–6, pp. 133–136). An illustrated survey of the industrial applications of electrically heated furnaces and plant for the heat-treatment, reduction, and surface hardening of steel forgings, stampings, and sheets is presented.—P. F.

Flame Hardening of Large Surfaces. J. J. Barry. (Welding Journal, 1951, vol. 30, Feb., pp. 111–116). Fundamental principles governing flame-hardening are discussed and a historical review is given.—U. E.

Commercial Flame Hardening. E. J. Cox. (Welding Journal, 1951, vol. 30, Mar., pp. 229–233 ; Australasian Engineer, 1951, June 7, pp. 62–63). Suitable equipment for commercial flame-hardening is described.—U. E.

Selection of Alloys for Dry-Cyaniding and Gas-Carburizing Applications. C. E. Wenger and G. C. McCormick. (Industrial Heating, 1950, vol. 17, Oct., pp. 1751–1754). This article reviews problems in the operation of dry-cyaniding and

gas-carburizing furnaces caused by the shortage of nickel. It is recommended that for certain parts 35/15 Ni-Cr alloys should be replaced by 20/26 alloys.—J. A. L.

Uneven Hardness Gradients in Quenched Steels. H. O'Neill. (Metallurgia, 1951, vol. 44, July, pp. 29–31). Jominy hardenability curves occasionally show an unusual increase in hardness, and similar effects have been found in hardness surveys of welded joints and in steel rails which have had a special hardening treatment applied to the head. It is suggested that the original austenite transforms locally in the intermediate range:—E. T. L.

Ford Camshafts Flame or Induction Hardened. (Industrial Heating, 1951, vol. 18, Mar., pp. 422–430). This article describes a simple and rapid method of flame-hardening camshafts, at the Ford Motor Co., Dearborn, Mich. The method processes 940 pieces every 8 hr. using two units.—J. A. L.

The Main Parameters for High-Frequency Hardening of Tool Steel. I. N. Kidin. (Stanki i Instrument, 1948, No. 6, pp. 10–13). [In Russian]. An account is given of a laboratory-scale investigation on the effects of heating temperature and rate on the structure and hardness of tool steel, containing not more than 1·5% of alloying elements, induction-heated and water-quenched.—S. K.

Induction Heating and Its Applications. R. Lethen. (Elektrowärme Technik, 1951, vol. 2, No. 2, pp. 30–37). The principles of induction heating are explained, and the design and performance of induction furnaces considered. The applicability of induction furnaces for the surface hardening of rails, the melting of steel and light metals, and the heating of boilers is discussed and illustrated by numerous drawings and photographs.—P. F.

High-Frequency Heating. E. Cometta. (Rivista di Meccanica, 1951, vol. 2, Apr. 25, pp. 5–11). [In Italian.] The author describes the theoretical principles and practical applications of high-frequency heating distinguishing between inductive heating of conducting materials and capacitive heating of insulators. Consideration is given to high-frequency generators, their design and operating characteristics. Applications of this form of heating for the heat treatment of small parts of machine tools are described.—M. D. J. B.

Continuous Annealing of Strip Steel at Dominion Foundries and Steel, Ltd. W. R. Weir. (American Iron and Steel Institute: Industrial Heating, 1951, vol. 18, Mar., pp. 457–472). **Continuous Annealing Arousing Industry Interest.** W. R. Weir. (Steel, 1951, vol. 128, Apr. 30, pp. 68–74, 84). The construction, operational features, and the results obtained by the continuous annealing process for strip steel are discussed. Details concerning furnace atmosphere and annealing temperatures are also given.—J. A. L.

New Bright Normalizing Furnace. (Iron and Coal Trades Review, 1951, vol. 162, Apr. 13, p. 844). A brief description is given of a new G.E.C. roller-hearth furnace installed at Effingham Steel Works Ltd. for continuous normalizing treatment of steel strip in an atmosphere of partially burnt town gas. The heating zone is divided into three independently and automatically controlled sections, and two cooling zones are provided which enable the strip to be handled on emerging from the furnace. The furnace is rated at 220 kW. and has a nominal capacity of 10 cwt. of strip per hour.—G. F.

FORGING, STAMPING, DRAWING, AND PRESSING

Investigations into the Effect of Non-Metallic Inclusions on the Hot-Workability of Steel. F. Rapatz and M. Strobich. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 374–375). Forging tests on mixtures of iron powder with various proportions of the non-metallic inclusions CaO, SiO_2, CaF_2, Na_2CO_3, Na_2SiO_3, showed that the lower the melting point of the included material the greater is the difficulty in hot-working, irrespective of whether the inclusions are acid or basic. The poor forgeability of steel containing acid inclusions is attributed to the low melting points of the silicates the added material. It is found that bars prepared from steel powder by hot-working have almost the same mechanical properties as those prepared by casting and rolling.

The Manufacture, Testing and Inspection of Turbine and Turbo-Alternator Rotors for Power Stations. H. H. Burton. (Metallurgia, 1951, vol. 44, July, pp. 22–28). The author discusses the choice of steel composition, the melting (either acid open-hearth or basic electric furnace), reheating and forging of alloy steel for rotors. Then he considers heat-treatment, rough machining, final heat-treatment, testing and inspection. This last is by sulphur printing, the use of a boroscope, and ultrasonic crack detection.—E. T. L.

Machinery and Methods in Forging. R. Bianchi. (Rivista di Meccanica, 1951, vol. 2, May 10, pp. 5–9). [In Italian]. A description is given of the methods of hot and cold forging and the plastic behaviour of metals under pressure. Different types of forging equipment from simple manually operated hammers to large vertical and horizontal presses are considered. The structural and mechanical properties of forgings are discussed.—M. D. J. B.

Hollow Steel Propeller Blades for Aircraft. (Engineering, 1951, vol. 172, Aug. 10, pp. 161–163; Aug. 17, pp. 193–194; Aug. 24, pp. 225–227). This article describes a method developed by de Havilland Propellers, Ltd., Hatfield, for manufacturing hollow steel propeller blades. The method consists of brazing a forged steel load-carrying core tube to a sheet-metal shell. The article, with many technical details, is amply illustrated and covers the development, manufacture and testing of hollow propellers.—M. D. J. B.

Production Problems—VI: Failure of Steel Sheet during Pressing. (Iron and Steel, 1951, vol. 24, July, pp. 335–336). This article describes an investigation into the cause of failures encountered during the blanking and pressing of $\frac{3}{16}$ in. steel plate. No significant difference was observed in the materials or in the gauge of the good and bad original sheet specimens, although there was considerable thinning at the point of fracture. The difference in mechanical properties was not sufficient to account for the failure. Tooling was the primary cause of failure; a punch of larger radius should be used to avoid serious reduction in thickness at the point where failure ultimately takes place.—G. F.

Production at the Pressed Steel Company. (Welding and Metal Fabrication, 1951, vol. 19, Mar., pp. 84–90). The manufacture of all-welded pressed steel motor-car bodies with unit construction of chassis and body is described. The profile milling machine, crank press, and a fully automatic spot-welding machine are illustrated.—U. E.

Design and Production of Sheet-Metal Parts. C. S. Beers. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1951, vol. 91, July 5, pp. 20–22). Defects due to poor design and bad drawing are described and the need for careful designing of tools for producing drawn pressings is emphasized. When welding has to be employed, flash welding will give the best results and the troubles associated with other welding methods are pointed out.—J. E. W.

The Influence of McQuaid-Ehn Grain Size on the Drawing Properties of Patented Steel Wire. P. Günther. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 149–154). Drawing tests have shown that, up to 85% total reduction, there is no difference in the properties of wires drawn from coarse, medium and fine-grain steels (grain sizes, 2, 4–6, and 7–8). It is known from the literature and experience that for heavy reductions, coarse-grained austenitic steels are superior to others and that the production of high-tensile wire with good drawing qualities is possible only with such steels. This needs to be confirmed by suitable research, which is, however, rendered difficult by the fact that steel melting practice in Germany produces few coarse-grained austenitic steels.—J. P.

Drawing Wire from Steel Contaminated with Chromium and Copper. W. Püngel. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 143–148). Difficulties have occurred recently in fabricating wire when the contents of chromium or copper in steel have exceeded certain values. The material exhibits poor drawability after patenting and possesses inadequate strength after drawing, or it fractures prematurely during working. It is not the actual content of chromium that is responsible, but the form in which it is present. The detrimental effect is small if the chromium content is less than 0·10%. Increasing chromium contents increase the time required for isothermal transformation of austenite and thus chromium steels need longer patenting than those without chromium. Thin wires can be drawn from otherwise unfavourable material if it is coarse-grained. Transverse cracking of wires appears to be associated with increasing contamination of steel with copper. Other factors such as microstructure and drawing lubricant can accentuate the cracking. It can be avoided by keeping the copper content below 0·15–0·2%, keeping scaling to a minimum, and reducing the heating temperature and stresses before the wire enters the lead bath.—J. P.

ROLLING-MILL PRACTICE

Cold Rolling Technique Section VI—Methods of Calculating Roll Force and Torque Based on Theories of Rolling. H. Ford. (Sheet Metal Industries, 1950, vol. 27, Feb., pp. 101–108; Mar., pp. 197–202, 207; June, pp. 485–491; 1951, vol. 28, Jan., pp. 5–11, 18; May, pp. 427–434, 438; Aug., pp. 693–704). Conclusion of a series of articles (*see* Journ. I. and S.I., 1950, vol. 166, Nov., p. 264).

Acceleration Characteristics of Tandem Cold Reduction Mills. W. R. Harris and R. W. Moore. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 63–72). After a brief review of the development of tandem cold reduction mills the authors discuss, from the electrical drive standpoint, the problems of acceleration, deceleration, emergency stopping, and gauge control during periods of changes in speed. A new concept of measuring the accelerating ability of motors operated in tandem is suggested.—M. D. J. B.

Shepcote Lane Rolling Mills: Progress Report on New Plant for Rolling Stainless Steel Sheets. (British Steelmaker, 1951, vol. 17, July, pp. 370–375). A detailed description is given of the principal equipment and layout of the Shepcote Lane Rolling Mills, which will come into full production early in 1952. The plant, jointly owned by Firth-Vickers Stainless Steels Ltd. and Samuel Fox and Co. Ltd., will comprise hot and cold rolling mills with all ancillary equipment; it will produce stainless steel sheets from cold-rolled, softened, and descaled strip up to 1 m. in width.—G. F.

Production and Metallurgical Characteristics of Mining Hollow Drill Steel in Australia. D. Clark. (Australian Institute of Mining and Metallurgy: Metallurgia, 1951, vol. 43, Mar., pp. 112–117, Apr., pp. 161–166). After a brief survey of the development of hollow steel drill bits, used to reduce weight and conduct water for suppressing dust, this article considers typical analyses, and the mechanism of failure. Previous and modern methods of bit manufacture are then given in some detail, particularly the rolling process.—E. T. L.

Electrical Drive for 56-in. Five-Stand Tandem Cold Reduction Mill. R. A. Harvie. (Association of Iron and Steel Engineers, Yearly Proceedings, 1950, pp. 453–458). The author describes the main drive electrical system of the Steel Company of Canada 5-stand tandem mill with special reference to novel features in the design. The separate generator system, main circuits, control system, master controller and stand control are considered in detail.—M. D. J. B.

Electrical Equipment for Cold Rolling and Finishing Department. M. A. Leishman. (Association of Iron and Steel Engineers, Yearly Proceedings, 1950, pp. 445–452). The author describes the new cold rolling and finishing departments of the Steel Company of Canada Ltd. which began operation in 1948. Technical and operational data are given of the plant which comprises a pickling line, a five-stand 56-in. temper mill, two tinplate cutting-up lines, a side trimming line and a sheet shear line.—M. D. J. B.

Noncontacting Thickness Gages for Flat Rolled Steel Products. W. A. Black. (American Iron and Steel Institute, May 23–24, 1951, Preprint). This paper summarizes the results obtained with radiation gauges for continuously measuring the thickness of strip in hot molls. Two types of gauge have been developed, using X-ray and β-ray radiation respectively, and in each case the circuits used, installation details, thickness range, operating experiences, and safety precautions are discussed. The advantages obtained include greater accuracy, immediate and continuous gauge readings which are insensitive to strip vibration, and a reduced number of rejections.—G. F.

Application of Time Studies in Iron and Steelworks. S. Wislocki. (Boletim da Associação Brasileira de Metais, 1951, vol. 7, Jan., pp. 36–48). [In Portuguese]. Special attention is paid to rolling. A complete example is considered, accompanied by charts, of the application of time studies to production planning, and the calculation of wage incentives.—R. S.

MACHINERY FOR IRON AND STEEL PLANT

Plain Bearing Recommended Practice—A.I.S.E. Recommended Practice No. 1, 1951, April 29). (Iron and Steel Engineer, 1951, vol. 28, July, pp. PB13–PB37). This is a tentative specification for steel plant plain bearings prepared by a committee of the Association of Iron and Steel Engineers. The paper deals in detail with the fundamentals of bearing friction, beneficial effects of lubricants on bearing surfaces, principles of good plain bearing design, oil film formation, oil film design methods, oil grooving, grooving comparisons for oil and grease, calculation of bearing areas and the mathematical evaluation of bearing types. In addition the properties of metal bearing materials are considered and recommendations made for the pouring and casting of bearings. Conversion tables are given for kinematic and Saybolt universal viscosities.—M. D. J. B.

Motor Inspector Training. G. M. Kennedy. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 74–76). This paper gives a brief review of methods adopted at the Carnegie-Illinois Steel Corp. for training men for maintenance jobs, especially for motors, generators, controls, switches, circuit breakers, and control panels.—M. D. J. B.

Transformer Oil in the Steel Plant. J. F. Boal. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 97–103). The author discusses the improvements made in transformer design and in particular the provisions for protecting the oil from contact with air, moisture and other deleterious external materials. Transformer oil problems are considered in detail.—M. D. J. B.

Sliding Contacts for Transfers of Electrical Energy for Industrial Systems. H. Y. Mageoch. (Association of Iron and Steel Engineers, Yearly Proceedings, 1950, pp. 742–748). After giving a classification of collector systems in relation to the types of conductor used, the author describes the various forms of collectors available, collector shoe material, and insulators. The selection of suitable material for special conductor systems is discussed.—M. D. J. B.

Maintenance of Ore and Coal Bridges. S. M. Suplick. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference, 1950, vol. 9, pp. 194–203). The Engineering and Inspection Bureau makes about three yearly inspections of 250 movable bridges for coal and ore, chiefly in the Great Lakes area. The entire structures are inspected for faults, and the various safety devices are tested. The factors upon which the safety of a bridge depends are reviewed, and rules are given for the care of bridges and foundations.—T. E. D.

WELDING AND FLAME-CUTTING

Some Research Techniques for Studying Arcs in Inert Gases. R. H. Gillette and R. T. Breymeier. (Welding Journal, 1951, vol. 30, Mar., pp. 146s–152s). Several techniques are described for the determination of fundamental data on inert gas-shielded arcs. Short, high-current, atmospheric pressure arcs in argon or helium were studied. In the case of arcs with consumable electrodes ultra-slow motion picture investigations of metal transfer characteristics under different welding conditions are discussed.—U. E.

Arc Welding Equipments and New French Standards Concerning Them. A. Gaubert. (L'Ossature Métallique, 1951, vol. 16, June, pp. 277–286). The principal features of arc-welding equipments and the peculiarities of their performance as determined by the type of electrode used are discussed, and the influence of different welding techniques on the design of the equipment is considered. The new French arc-welding standards are explained and some of their aspects are compared with those in force in Europe and America.—P. F.

Normalization of Oxy-Acetylene Welding Work. I. S. Smirnov. (Avtogennoe Delo, 1948, No. 5, pp. 28–31). [In Russian]. Norms for various oxy-acetylene welding operations are given, based on time and motion studies.—S. K.

Procedure Approval Tests. S. S. Katsef. (Welding Journal, 1950, vol. 29, Dec., pp. 1070–1077). Examples of forms for procedure approval tests and flow sheets for the performance of tests and recording results are given; these are used in the production of welded naval equipment. Information is obtained on joint design, welding technique, preheat temperature, interpass temperature, post-heat-treatment, and composition of the weld metal.—U. E.

Flash Butt Welding of Steel. L. Sanderson. (British Steelmaker, 1951, vol. 17, Apr., pp. 207–211; May, pp. 255–259; June, pp. 320–323). The author first describes the development of the flash butt welding process and gives a full description of the component parts of a typical welding machine. Certain metallurgical aspects of this type of welding are then discussed, and an account is given of difficulties commonly encountered. The fundamental principles of the process are considered in detail, the nature of the characteristic flashing action being explained.—G. F.

The Industrial Use of Flash Welding, Dealing in Particular with Ferrous Materials. (Transactions of the Institute of Welding, 1951, vol. 5, Feb., pp. 135*r*–146*r*). The flash welding process as applied to the welding of ferrous metals is discussed and recommendations on procedure and correct power supply are made.—W. E.

Edge Preparation of Plate for Welding. C. A. Heffernon. (Welding Journal, 1951, vol. 30, Mar., pp. 221–228). A description is given of the flame-shaping of plate edges for welding to assure uniformity to cut surfaces and correct alignment. Cutting machines are illustrated.—U. E.

Automatic Control in Welding Practice. K. K. Khrenov. (Avtogennoe Delo, 1948, No. 6, pp. 1–10; No. 7, pp. 9–15). [In Russian]. In the first part of this article the broad aspects of automatic process-regulation are considered, and the main components of any automatic controlling system are listed and explained. The second part deals with the stability of regulating systems, the classification of automatic equipment for electric arc welding, and general requirements and performances of arc-welding machines. Detailed examinations are made of the main types of automatic welding machines with constant arc-voltage and continuous action, this consideration being extended in Part III to include thyratron control.—S. K.

Fabrication of Corrosion-Resistant Metals—The Importance of Metallurgical Control. J. F. Lancaster. (Welding and Metal Fabrication, 1951, vol. 19, June, pp. 202–209). The importance of metallurgical control in the welding of stainless steel is pointed out. Macrographs are shown of argon arc weld deposits, and a table gives efficiency data.—U. E.

Aircomatic Welding of Nickel and Stainless-Clad Steels. T. T. Watson and R. R. Rothermel. (Welding Journal, 1951, vol. 30, Mar., pp. 116s–122s). The aircomatic welding process as applied to nickel and stainless-clad steels employs a consumable electrode of filler metal which is fed into the arc stream where it is completely enveloped by an inert atmosphere. The equipment can be operated manually, semi-automatically, or fully automatically. Procedures were developed for welding clad steel plates up to $\frac{3}{4}$ in. thick.—U. E.

Argon-Arc Welding of Thin Stainless Steels. A. Ya. Brodskii. (Avtogennoe Delo, 1948, No. 5, pp. 6–8). [In Russian]. After a brief account of the advantages of argon-arc welding and the theory of the process, the torches, transformers and electrodes used are considered. Tests showed that tungsten electrodes were better than carbon for welding stainless steels, the permitted diameter of electrode for steel 0·8–1·5 mm. thick being 2–2·5 mm., and that dried argon (13–14% nitrogen) could be used satisfactorily.—S. K.

Welding Stainless Steel Containers to Meet Sanitary Standards. P. H. Mounts. (Welding Journal, 1951, vol. 30, Jan., pp. 33–39). The welding of dairy equipment is described. U. E.

Physical Metallurgy of Austenitic Stainless Steels. H. Thielsch. (Welding Journal, 1950, vol. 29, Dec., pp. 577s–621s). Published and unpublished data on the weldability of chromium-nickel stainless steels are reviewed. There are 257 references.—U. E.

New Types of 'Avesta' Stainless Electrode. Bjorkröth. (Acciaio Inossidabile, 1951, vol. 18, Jan.–Feb., pp. 6–12). [In Italian]. The author describes in detail the metallurgical and mechanical characteristics of the latest type of stainless steel electrodes fabricated by the Avesta steelworks. The technique to be used with these electrodes is considered. The stability of the arc, method of holding the electrode, behaviour of the deposited metal, speed of deposit, de-slagging, penetration, and corrosion resistance are dealt with.—M. D. J. B.

From Ingot to Weldment. (Welding and Metal Fabrication, 1951, vol. 19, May, pp. 167–173). The fabrication of steel plates by welding by the Lukens Steel Co., Coatesville, Pa., is described.—R. A. R.

Evaluation of Welded Ship Plate by Direct Explosion Testing. G. S. Mikhalapov. (Welding Journal, 1951, vol. 30, Apr., pp. 195s–201s). The effect of variation in welding procedure on notch sensitivity of two types of ship plate (manganese steel with 0·05 and 0·22% Si respectively) has been investigated. The performance of plates of killed fine-grain steel appears to be slightly but not significantly better than that of semi-killed steel. The cleavage type of fracture occurred in all steels. Both killed fine-grain and semi-killed steels when welded with E6010 electrodes failed in a brittle manner at temperatures as high as 10° F. as compared with −80° F. for the brittle fracture of unwelded plate. Weldability of semi-killed steel welded in six passes with 2%-Mn electrodes by the submerged arc process is comparable to that of fully-killed steel welded with E10016 electrode.—U. E.

Welding of High-Temperature High-Pressure Piping. L. C. McNutt. (Welding Journal, 1951, vol. 30, Apr., pp. 325–330). Alloy Steels used for high-temperature, high-pressure piping are divided into six groups according to their chromium content; and their weldability is outlined.—U. E.

Welding High-Temperature Austenitic Steel Piping. R. W. Emerson and M. Morrow. (Welding Journal, 1951, vol. 30, Jan., pp. 15s–39s). The welding of 18%-Cr, 10%-Ni columbium-stabilized austenitic stainless steel was investigated. Special reference is made to problems of sigma phase and micro-cracks. It was found that a content of 3·5% ferrite and 0·5–0·6% silicon in the weld deposit gave satisfactory properties. When submerged-arc welding was carried out with 29/9 Cb-stabilized electrode the ferrite content was about 20–25% resulting in a weld having adequate strength and ductility. The 19/9 electrode produced micro-cracks. It was found that in austenite deposits high in ferrite, the change from ferrite to the brittle sigma phase was 85% complete in as few as 300 hr. at 1100° F. This transformation takes place more slowly in the 1100–1600° F. range if the weld deposit is previously given a 1950° F. water-quench. A number of micrographs of the deposits are given.—U. E.

Welding Procedures for High-Pressure High-Temperature Steam Piping. N. L. Navarre. (Welding Journal, 1951, vol. 30, Jan., pp. 1s–9s). The welding of chromium-molybdenum steel tubing and of 18/8 steel tubes containing columbium is described. Tests of composite joints between 2·25%-Cr–1%-Mo steel and 18/8 steel wherein thermal shock was employed indicated that 19%-Cr–9%-Ni (Cb) weld metal was more suitable than 25%-Cr–20%-Ni steel.—U. E.

The Weldability of Chromium–Molybdenum Steels. H. F. Tremlett. (Transactions of the Institute of welding, 1950, vol. 13, Oct., pp. 143–156). The weldability of chromium–molybdenum steels used for large vessels or structures in the oil-refining industry is discussed. It was found that weld-joint cracking with chromium-molybdenum electrodes, whether in weld metal or heat-affected zone, is eliminated by preheating to 150–200° or 200–250° C. according to composition. This is effective despite the presence of martensitic structures in the heat-affected zones of the steels. Maximum carbon contents are suggested.—U. E.

Welding Quality Control in a Petroleum Refinery. A. F. Blumer. (Welding Journal, 1951, vol. 30, Mar., pp. 235–243: Australasian Engineer, 1951, June 7, pp. 65–68). Welding quality control consists of qualification testing of welding operators, continued sampling and welding inspection on jobs in progress, testing and selection of suitable electrodes, adherence to carefully developed welding procedures and job specifications, and evaluation and use of new developments in the field of welding.—U. E.

The Heat Treatment of Welds in Pipelines. A. H. Goodger. (Institution of Heating and Ventilating Engineers: Engineering, 1951, vol. 172, July 27, pp. 125–127; Aug. 3, pp. 157–158; Aug. 10, p. 191). The author discusses in detail the advantages of heat-treating welds in pipes, the object of the treatment being to prevent subsequent cracking or brittle fracture from suddenly applied loads or shocks. The author distinguishes between preheating in oxy-acetylene welding to aid the welder to obtain good root fusion in a thick-walled pipe, and in arc welding to prevent cracking as a result of hardening, and post-heating or normalizing used with both oxy-acetylene and arc welding. Technical data are given with numerous illustrations and microphotographs.—M. D. J. B.

Mechanical Properties of Welded Joints Made by Gas Pressure Welding during the Construction of Large Pipelines. A. S. Falkevich. (Avtogennoe Delo, 1948, No. 4, pp. 20–22). [In Russian]. On the basis of tensile, bend, and impact tests and metallographical investigations of specimens of gas pressure-welded, thin-walled tubes it is concluded that: (1) The properties of the welded joints are entirely satisfactory for pipelines, and they have especially high yield strengths; (2) their plasticity is low, but can be increased by normalization; and (3) the quality of the weld depends to a great extent on correct assembly and preparation for welding. The suitability of various testing methods for joints of this type is discussed.—S. K.

Statistical Analysis of the Quality of Tubes and Welded Joints in Gas Pipelines. S. M. Skorodzievskii. (Avtogennoe Delo, 1948, No. 4, pp. 23–24). [In Russian]. The results are presented of a statistical analysis of a large number of test results on arc and gas pressure-welded tubes of Russian and foreign manufacture. These show that, compared with arc-welded joints, gas pressure-welded joints tend to have higher yield strength but poorer bending properties.—S. K.

Present Problems in the Welding of Main Pipelines. A. S. Falkevich. (Avtogennoe Delo, 1948, No. 5, pp. 3–5). [In Russian]. Gas, manual arc, automatic submerged arc and automatic gas pressure welding as used in pipeline construction are briefly considered, together with a possible method using induction heating. The adoption of methods involving continuous building up of the pipeline with overhead welding of seams is recommended.—S. K.

Welding of Steel Plate Linings for Water Tunnel Reinforcement for a Power Station. R. Malisius and W. Liebig. (Schweissen und Schneiden, 1951, vol. 3, Apr., pp. 103–107). Steel plate linings, 14 mm. thick, used to reinforce a tunnel 6 m. dia. for water were welded by the Ellira submerged arc process. The economic advantage gained by using this process as compared with ordinary arc welding is pointed out.—U. E.

Welding in Gas Turbines for Use on Land : Application to the Manufacture of Parts Operating at High Temperatures. J. M. Robertson. (Transactions of the Institute of Welding, 1951, vol. 14, June, pp. 68–73 : Iron and Coal Trades Review, 1951, vol. 163, July 20, pp. 133–139). The author reviews the metallurgical problems inherent in the welding of components of gas turbines for land use, and discusses the application of the welding process to the manufacture of parts operating at high temperatures. The selection of materials for the various components is considered, and specific welding problems pertaining to ferrite and austenitic steels are discussed.—G. F.

Keeping Tractors in Service. C. B. Clason. (Welding Engineer, 1951, vol. 36, Aug., pp. 26–29). A submerged-arc welding head in conjunction with a motor-driven positioner carries out automatic hard-facing of tractor rollers and idler wheels. On rollers, the rod is a mild steel tube containing the alloying elements, chromium, molybdenum, and vanadium, and on the idlers a chromium–vanadium steel wire is used. The rod is arc-deposited at 30 in. of bead per min. and as many as six passes are used on badly worn rollers. No subsequent grinding is necessary.—M. R.

Building Up Manganese Steel Parts by Welding with Wear-Resisting Steel. W. Hummitzsch and A. Schmidt. (Schweissen and Schneiden, 1951, vol. 3, May, pp. 147–150). The building-up of manganese steel by welding with chromium steel is described. Results obtained with crushing machinery parts are discussed.—U. E.

Investigation on Building-Up of Rails by Welding. K. Wellinger and H. Gaisser. (Schweissen und Schneiden, 1951, vol. 3, June, pp. 173–178). The building up of rails by welding using chromium–manganese–nickel steels is described. Good wear-resistance was obtained.—U. E.

Hardfacing—A Design Tool. J. J. Barry. (Machine Design, 1951, vol. 23, Mar., pp. 114–119). The author discusses the advantages and methods of hard-facing and tabulates the characteristics and uses of the following alloys suitable for facing by welding : (1) High-carbon low and medium alloy steels ; (2) alloy cast iron ; (3) high-carbon chromium and chromium-nickel steels ; (4) high-manganese steel ; (5) high-chromium cast iron ; (5) cobalt-base alloys ; and (7) tungsten carbide.—E. C. S.

Hard-Facing of Steam Valve Seats and Disks. O. E. Swenson. (Welding Journal, 1950, vol. 29, Dec., pp. 1053–1058). An outline is given of the general welding procedure and fundamental differences in heating effects of low, medium, and high-velocity oxy-acetylene burner nozzles. It is shown that different overlay compositions, such as Cr–Ni–B, Cr–Co–Ni–Mo, and Co–Cr–W may be interchanged when flame ratios and deposition conditions are controlled. Testing methods for determining hot hardness, hot impact values, and steam tightness are given.—U. E.

New Production Applications of Hardfacing. E. C. Hurt. (Welding Journal, 1950, vol. 29, Dec., pp. 1082–1086). Automatic and semi-automatic equipment for the application of hard-facing is described and reference is made to the usefulness of the inert-gas-shielded-arc welding process.—U. E.

Hardfacing : Applications to the Iron and Steel Industries. P. L. Pocock. (Iron and Steel, 1951, vol. 24, July, pp. 232–326). The author discusses the advantages obtained by ' hard-facing ' machine parts which are subject to corrosion, abrasion, and friction. Particular attention is given to Stellite (Co–Cr–W alloy), and the base materials which are suitable for hard-facing are mentioned. Detailed descriptions of the oxy-acetylene and metallic arc methods of applying Stellite are given.—G. F.

Improved Double-Flame Welding Torches. G. K. Krekeler and H. Kunz. (Schweissen und Schneiden, 1951, vol. 3, May, pp. 142–147). A double-flame burner for fusion welding is described. Welding time was shortened by 40%, and a decrease of 30% in weight of filler rod and 20% in gas consumption were obtained. Economic advantages are discussed.—U. E.

Welding with Argon as a Protective Shield. H. Bühler and W. Günther. (Schweissen und Schneiden, 1951, vol. 3, Apr., pp. 110–112). This is a review of the development of the argon-arc welding process. There are 37 references.—U. E.

The Weight of Weld Seams. H. v. Neuenkirchen. (Schweissen und Schneiden, 1951, vol. 3, Apr., pp. 108–110). A mathematical representation is given to determine the weight of butt and fillet welds. With the introduction of a ' reducton factor ' more accurate values are obtained.—U. E.

The Spot Welding of Steel Plates Using a Multiple Impulse Method. F. Rosenberg. (Schweissen und Schneiden, 1951, vol. 3, Apr., pp. 115–116). A description is given of a multiple impulse method used in spot welding. The heat which is produced on the surface by the flow of current through the plate is conducted away by water-cooled electrode tips after each impulse while the current is not flowing. The short interval between two current impulses prevents the heat inside the plate from escaping and this leads to a concentration of heat at the spot to be welded. Steel plate can therefore be successfully spot-welded by the new method.—U. E.

Tensile Tests of Single Fillet Welds of Different Dimensions. H. Dienst. (Schweissen und Schneiden, 1951, vol. 3, Apr., pp. 112–114). Tensile tests on **T**-joints welded on one side gave poor results ; complete penetration is necessary to obtain a weld of high strength.—U. E.

Tensile Properties of Mild Steel Weld Metal at High Temperatures. J. G. Ball and K. Winterton. (Transactions of the Institute of Welding, 1950, vol. 4, Dec., pp. 104*r*–124*r*). Hot-cracking in mild-steel weld metals was investigated. In the range 900–1100° C. all mild-steel weld metals tested were found to have low ductility compared with the values at higher and lower temperatures. The presence of iron oxide in the weld metal showed no influence on ductility. Percentage and constitution of oxide inclusions in three of the weld metals were determined and weld metal structures examined under the electron microscope.—U. E.

Ductility of Mild Steel Welds near the Solidus. E. C. Rollason. (Transactions of the Institute of Welding, 1950, vol. 4, Dec., pp. 125*r*–128*r*). The results of some simple hot tensile tests on core wire and weld metal show a lowering of ductility at 1250–1280° C. Welds graded according to this criteria are in correct order as regards hot-cracking during welding. Increase of manganese in one type of electrode maintains hot ductility to a higher temperature.—U. E.

Relative Strain-Aging Tendency of Weld and Base Metal. R. W. Fountain and R. D. Stout. (Welding Journal, 1951, vol. 30, Jan., pp. 43s–46s). An investigation was carried out to separate the relative tendencies of the weld-metal heat-affected zone and the base metal to obtain a change in ductility after straining and ageing. A loss of ductility and notch toughness in welded plate due to prestraining and ageing was obtained. No effect was observed when the notch was placed entirely in weld metal or in unwelded plate. It appears that the heated zone rather than weld metal is responsible for the loss of ductility and toughness caused by prestraining and ageing.—U. E.

Spot Welding of SKhLF Steel. A. S. Gelman and S. S. Astafev. (Avtogennoe Delo, 1948, No. 4, pp. 1–10). [In Russian]. An account is given of an investigation of the spot welding of a steel with the following composition : C 0·12–0·13%, Si 0·31–0·37%, Mn 0·52–0·58, S 0·030–0·025%, P 0·10–0·11%, Cr 0·55–0·56%, Ni 0·45–0·31%, and Cu 0·68–0·50%. Sheets 4 and 8 mm. thick were welded on a 150-kVA, welding press having specially hard electrodes, and were then subjected *in situ* to heat-treatments involving 70,

78, 85, and 93% of the welding current. Welding conditions were varied widely. The results of mechanical tests and metallographic investigations are related to the conditions of welding and show the effectiveness of this heat-treatment. The optimum welding conditions are listed.—S. K.

High-Speed Resistance Seam Welding. G. V. Nédzvetskii. (Avtogennoe Delo, 1948, No. 4, pp. 10–11). [In Russian]. The modification of equipment and procedure necessary for an acceleration of the resistance seam welding of sheets of low-carbon steel, brass, and zinc was studied. To deal with steel sheets 0·3 mm. thick, roller electrodes 315 mm. in dia. with edges sharpened to 90° were used, which, with modifications of the equipment enabled tight seams to be produced at a welding speed of 39 m./min.—S. K.

The Preheating Process and Rate of Cooling of the Metal in Welding. L. A. Fridlyand. (Avtogennoe Delo, 1948, No. 4, pp. 12–16). [In Russian]. A theoretical examination is made of the influence of preheating on the thermal and hardening processes accompanying the arc-welding of steel.—S. K.

Coatings for Steel Electrodes for Welding Cast Iron. P. S. Elistratov. (Avtogennoe Delo, 1948, No. 4, pp. 17–19). [In Russian]. Plates of grey cast iron were bead-welded using low-carbon steel electrodes with various coatings. Best results were obtained with coatings containing 50–40% of graphite and 50–60% ferrosilicon.—S. K.

Make Repair Welds on Large Gray Iron Castings. J. H. Walsh. (American Foundryman, 1951, vol. 19, Jan., pp. 52–55). Experiments are described which were designed to determine a technique for repairing large iron castings by welding. Preheating in a furnace was better than preheating with a welding torch.—E. J. D. S.

Removes Casting Defects Quickly. R. H. Herrmann. (Foundry, 1951, vol. 79, Mar., pp. 164, 166–167). A patented oxygen-jet electric-arc torch is described, by which it is possible to remove casting defects at the rate of 1 cu. in. of metal in 30 sec.—E. J. D. S.

Making Milling Cutters by Electric-Arc Hard-Facing with Specially Coated Electrodes. Z. M. Ryzhik. (Avtogennoe Delo, 1948, No. 4, pp. 22–23). [In Russian]. Details are given of the hard-facing of milling cutters in special copper moulds using coated low-carbon steel electrodes.—S. K.

Influence of Thermal Treatment on the Strength of Welded Spots in the Welding of Chromansil Steel. F. E. Trétyakov. (Avtogennoe Delo, 1948, No. 4, pp. 25–26). [In Russian]. The results are presented of an experimental investigation on the spot-welding of Chromansil steel. Plates 100 × 20 mm. and 1 to 3 mm. thick were spot-welded in standard machines with electrode pressures of 65–130 kg., with different types of heat-treatment before and after welding. The joints were subjected to mechanical tests and metallographic and X-ray investigation. It is concluded that: (1) The steel can be spot-welded both in the hardened and tempered states; (2) the overheating evident in the core of the spot can be eliminated by tempering; (3) the region of the spot is hardened; (4) the strength of the weld can be increased by heat-treatment; and (5) the welding time must be not less than 1·5 sec.—S. K.

Investigation of Crystal Structure of Seam Metal in Arc Welding. A. A. Alov and I. M. Vagapov. (Avtogennoe Delo, 1948, No. 6, pp. 10–15). [In Russian]. An investigation of the nature of the forces acting on the fused metal in arc welding, and of the crystal structure of the seam metal is reported. Special etching techniques were developed and applied to seams produced in various positions in steels and cast iron. Non-ferrous metals, such as silver and copper, were used to show the action of forces leading to the formation of the typical scaly structure of the seam. This structure can be attributed to the successive crystallization of individual waves, and that within a given wave the axes of the dendrites are not parallel.—S. K.

Influence of Surface Oxides on Pore Formation in Submerged-Arc Welding. K. V. Liubavskii. (Avtogennoe Delo, 1948, No. 6, pp. 15–20. [In Russian]. After a thermodynamical discussion of the mechanism of pore formation in the seam metal, experiments are described in which the influence of rust and scale and of the nature of the flux on this effect in the submerged-arc welding of steel was investigated. Conclusions are drawn on the relative pore-forming propensities of rust and scale.—S. K.

Deformation of Welded Joints during Automatic Submerged-Arc Welding. V. M. Rybakov. (Avtogennoe Delo, 1948, No. 6, pp. 20–24). [In Russian]. Experiments are described in which deformations at various distances from **butt-**, **T-**, and lap-welded joints were measured. For the butt welds, three types of steel in the form of plates 500 × 115 × 10 mm. were used and the deformation was measured after the deposition of a backing weld, after backing and automatic submerged-arc welding, and after manual welding. Two sizes of **T**-joint were welded, only one type of steel being used and the longitudinal deformation and bending being measured for manual and automatic submerged-arc welding.—S. K.

Submerged-Melt Welding with Multiple Electrodes in Series. A. R. Lytle and E. L. Frost. (Welding Journal, 1951, vol. 30, Feb., pp. 103–110). Advantages are gained by using the series-arc technique of submerged-melt welding. The depth of penetration into the base metal can be controlled. As weld-metal dilution can be maintained below 10% a high quality clad-steel structure can be welded at normal speeds by this process. The application of heat to the base plate can be limited and melting rate of rod is approximately doubled. For surfacing applications where high hardness is required, carbon retention in the deposited metal is much greater than in conventional single-electrode methods.—U. E.

Multiple Layer Submerged-Arc Welding of Pressure Vessels. L. C. Stiles and D. H. Curry. (Welding Journal, 1950, vol. 29, Dec., pp. 1065–1068). Multi-pass automatic welding of heavy pressure vessels is described. The use of the direct current method, reverse polarity, and a welding speed of 20–25 in./min. gave best results.—U. E.

General Procedures for Fabrication of Pressure Vessels. S. V. Williams. (Welding Journal, 1951, vol. 30, Jan., pp. 26–32). A general procedure for the fabrication of pressure vessels by fusion welding is outlined. Special attention is given to drawings, specifications, material lay-out, forming, fittings, assemblies inspection, stress relieving, and final testing.—U. E.

Submerged Arc Automatic Welding Equipment. (Motor Ship, 1951, vol. 32, July, p. 134). Brief details are given of two types of submerged-arc welding equipment manufactured by the Quasi-Arc Co., Ltd., Bilston. With one type the welding wire and Unionmelt flux are fed down a 20-ft. flexible tube to a small tool held by the operator. With the second type the tube is less bulky as it only guides the wire, a small flux container being mounted on the welding unit.—R. A. R.

Technique for the Repair of the Bottoms of Metal Tanks by Electric Welding. D. E. Bondarev. (Avtogennoe Delo, 1948, No. 5, pp. 20–22). [In Russian].

Some Cases of the Breakdown of Welded Storage Tanks at a Low Temperature. V. I. Shabalin. (Avtogennoe Delo, 1948, No. 6, pp. 29–30). [In Russian]. Five cases of cracking in welded storage tanks are examined; these occurred when air temperatures of −31 to −44° C. followed a relatively mild spell. It is concluded that these failures are to be attributed to the low temperature prevailing when they took place and not to temperature conditions at the time of welding.—S. K.

Lateral Contraction of Butt-Welded Seams in the Electric Welding of Very Thick Steel. V. L. Tsegelskii and V. I. Melnik. (Avtogennoe Delo, 1948, No. 6, pp. 31–32). [In Russian]. In the experiments described, steel plates 33 × 400 × 1000 mm. were arc-welded in the form of open double-**V** or open double-bevel joints with various gaps, bevel angles, and order of deposition of seams. The lateral contraction was measured in each case, and the results are compared with those calculated by the empirical formula $\alpha = (0{\cdot}6\,\alpha_1 k\frac{F}{\delta} + \alpha_2\Delta) \times 1{\cdot}3$, where α_1 and α_2 are coefficients, k is a coefficient depending on the type of electrode used, F is the cross-sectional area of the seam, δ is the thickness of the seam, and Δ is the seam width. With the appropriate values of the coefficients the experimental results were 20–25% higher than those calculated for the vertical double-**V** joints, but good agreement was obtained for horizontal double-bevel joints.—S. K.

Automatic Stud-Welding to Vertical and Overhead Surfaces. N. G. Ostapenko. (Avtogennoe Delo, 1948, No. 5, pp. 16–18). [In Russian]. An account is given of a gun which can be used for submerged-arc welding of studs to vertical or overhead surfaces, the flux being contained in a box of the appropriate shape attached to the gun. Tests showed that the total time per stud is approximately 12–15 sec., the welding time with a stud 12 mm. in dia. being 0·8 sec.—S. K.

A Tilter for the Automatic Welding of a Locomotive Boiler Assembly Joint. S. A. Goldenberg. (Avtogennoe Delo, 1948, No. 6, pp. 32–33). [In Russian].

The Heating of Metal by an Oxy-Acetylene Flame. N. N. Rykalin and M. Kh. Shorshorov. (Avtogennoe Delo, 1948, No. 7, pp. 16–21). [In Russian]. The heat flow round the point in a steel plate being heated by the flame and the temperature fields in the plate were studied. Using plates 300 × 200 or 200 × 200 mm., with welded-on thermocouples, the effects of the following factors were examined. Nozzle size, speed of torch movement, ratio of oxygen to acetylene, and plate thickness.—S. K.

Mobile Unit for the Butt-Welding of Tubes. M. B. Eksler. (Avtogennoe Delo, 1948, No. 7, p. 24). [In Russian]. A welding unit, self-contained except for power, is described, it is intended for the butt-welding of tubes 25 to 83 mm. in dia. The 100-kVA. welding machine, provided with pneumatic clamps, is mounted in the centre of the carriage near the controls, the rear portion being occupied by a compressor and cable and hose drums.—S. K.

Some Anti-Deformation Methods for Welded Ship Constructions. R. V. Vroblevskii. (Avtogennoe Delo, 1948, No. 7, pp. 25–26). [In Russian]. Deformations in welding and the means of preventing and removing them are considered in the light of experience in the welding of bulkheads.—S. K.

Evaluation of Changes in the Mechanical Properties of Metal after Welding by Testing for Cold-Working. S. M. Skorodzievskii. (Avtogennoe Delo, 1948, No. 7, p. 26). [In Russian]. In the work described, the change in hardness produced in a welded specimen by impacts was determined. Frequency curves were constructed for the hardening at different points on the specimen and the values of the cold-hardening coefficient were found for each point.—S. K.

Joining Cast Iron. C. O. Burgess. (Machine Design, 1951, vol. 23, Mar., pp. 129–131). Nickel-base electrodes permit the welding of grey iron to dissimilar metals. The joining of castings by welding may be desirable if the requirements of the part necessitate the integral combination of grey iron and another metal, or if casting in one piece presents problems which cannot be solved economically even by good foundry practice.—E. C. S.

Some Characteristics of Composite Tungsten Carbide Weld Deposits. H. S. Avery. (Welding Journal, 1951, vol. 30, Feb., pp. 144–162). Weld deposits from composite rods made by enclosing tungsten carbide granules in a mild-steel tube provide an outstanding level of abrasion resistance. The sheath tubing melts during welding and dissolves both tungsten and carbon to form a hard matrix that anchors the very hard granules in place. The matrix has characteristics that range from those of tungsten steel to cast-iron structures containing considerable secondary tungsten iron carbides. Hot hardness of arc welds is higher at 1200° F. and the Vickers microhardness of the primary tungsten carbide ($(Fe, W)_6C$, is near 1750 and the other matrix constituents are softer. Arc-welding may dissolve most of the primary carbides, especially if they are very fine, and result in loss of their distinctive abrasion resistance.—U. E.

Rotating Electrode in Manual Metal Arc Welding. G. S. Schaller. (Welding Journal, 1951, vol. 30, Jan., pp. 10s–14s). A holder for a rotating electrode was developed to facilitate striking the arc. This enables lighter-gauge sheet metal to be welded manually and less current is necessity to obtain a satisfactory weld.—U. E.

A New Liquified-Gas Blowpipe. H. Cordes, (Schweissen und Schneiden, 1951, vol. 3, June, pp. 185–186). Equipment for brazing using a propane–butane gas mixture is described. Directions are given for manipulation.—U. E.

ESAB'S Transformer TH 1000 for Several Welders. C. Hörnegren. (Svetsaren, 1951, vol. 16, No. 2, pp. 36–40). A description is given of a Swedish welding transformer which can carry a continuous load of 1000 amp. distributed over three phases. The welding current is at 79 V.—R. A. R.

A Gas Cutting Machine for Hot Cropping of Blooms. W. S. Walker and A. C. Gerrard. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 401–406). An oxygen cutter has been used to replace hot bloom shears for cropping. The machine has two cutters and two sets of control equipment. It is designed to cut alloy steels up to 30 in. thick at oxygen pressures of 20–35 lb./sq. in. The cutting speed can be varied from 4 to 40 in./min. and one complete operation for a 6¾ in. × 7 in. alloy bloom takes less than 45 sec. It can also be adapted for stainless-steel cutting. There is a fume-extraction fan. The cost per cut is less than for hot saws or shears.

Tracing Devices in Profile Flame-Cutting. R. O. Fish. (Welding Journal, 1950, vol. 29, Dec., pp. 1059–1064). Principles of operation of electronically guided template tracing devices and their preparation and application to profile flame-cutting are described. Advantages such as low cost of temporary and/or permanent templates, less storage space, and lower flame-cutting costs are pointed out.—U. E.

Investigation of an Electropyrolyser and the Electropyrolytic Gas. G. L. Petrov. (Avtogennoe Delo, 1948, No. 5, pp. 9–12). [In Russian]. An account is given of an experimental investigation into the generation of acetylene-containing gas from oil products by means of an electropyrolyser. The gas could be used for flame-cutting steel up to 30 mm. thick with an ordinary torch and up to 50 mm. thick with a special torch. It was also suitable for methods of metal treatment requiring relatively low temperatures and flame power. The specific consumption of oil during the normal working of the pyrolyser is about 0·83 kg./cu. m., the consumption of electrical energy being 2·7–2·8 kWh./cu. m.—S. K.

VNIIAvtogen S-4 Semi-Automatic Machine for Cutting Steel. (Stanki i Instrument, 1948, No. 5, p. 22). [In Russian]. A portable semi-automatic flame-cutting machine for cutting steel 10–100 mm. thick at speeds of 80–450 mm./min. is described.—S. K.

Flame-Cutting Steel with Propane. (Mitteilungen der B.E.F.A., 1951, No. 1 : Foundry Trade Journal, 1951, vol. 91, July 5, p. 10). A comparison of the cutting efficiency between acetylene and propane showed the superiority of acetylene.—J. E. W.

New Developments in Flame-Cutting Stainless Steel. G. E. Bellew. (Welding Journal, 1951, vol. 30, Mar., pp. 265–268). The flux-injection cutting process which uses a flux for the removal of oxides, is discussed. Standard cutting equipment with minor adaptations is used. The flux is fed by a variable speed vibratory hopper unit, directly into the cutting oxygen stream.—U. E.

MACHINING AND MACHINABILITY

Economic and Engineering Aspects of Machinability and Formability in Production Practice. D. F. Galloway. (Research, 1951, vol. 4, June, pp. 263–273). The necessity for efficiency in machining and forming operations is pointed out, and examples are given of cases where considerable savings of time and money have been made by relatively simple improvements in techniques. Researches already carried out, and types of research needed in the future, are reviewed, and examples are given. The author concludes that : Failure to use the best methods of metal cutting and forming is widespread and costly ; (2) even those actively concerned in metal-cutting practice and research have much to learn ; (3) present tests for machinability and formability are quite inadequate ; and (4) modern research shows promise of rapid advances.—C. J. B. F.

Effects of Chromium-Plating Cutting Tools. M. Armagnat. (Revue Générale de Méchanique, 1951, vol. 35, July, pp. 212–213). Chromium-plating of cutting tools reduces wear by friction, modifies the angle of cut, and the type of wear. In reducing the fluctuation of frictional forces, tool vibration is reduced.—R. S.

New Machines and Equipment for the Flame-Machining of Metals. V. S. Chernyak and Iu. Ya. Chafit. (Avtogennoe Delo, 1948, No. 6, pp. 25–29). [In Russian]. Descriptions are given of flame-machining equipment, designed by the All-Union Autogenous Metal Machining Research Institute, which has recently been applied industrially.—S. K.

Methodical Principles of Standardization and Normalization in Machine Tool Construction. M. R. Sum-Shik. (Stanki i Instrument, 1948, No. 3, pp. 4–9). [In Russian]. On the basis of experiments carried out over a number of years, the broad aspects of the standardization of machine tool construction are dealt with.—S. K.

New Method of Sharpening Drills. M. M. Neklepaev. (Stanki i Instrument, 1948, No. 5, pp. 10–13). [In Russian]. Details are given of a new shape of drill tip, developed at the Gorky Automobile Factory, and of the method of sharpening.

Fundamental Organizational Problems in Industrial Standardization. A. V. Vaksman. (Stanki i Instrument, 1948, No. 5, pp. 14–16). [In Russian]. The author describes his experiences in standardizing machine tool operation.—S. K.

Standardized Equipment for Drilling. V. F. Gushchin.

(Stanki i Instrument, 1948, No. 5, pp. 16–20 ; No. 6, pp. 18–19). [In Russian]. Details are given of standardized designs of jig for dealing with work 100–2000 mm. in size.—S. K.

Government All-Union Standards for Metal-Cutting Machine Tools. (Stanki i Instrument, 1948, No. 5, pp. 25–26). [In Russian]. A list of standard specifications is given dealing with the main dimensions of metal-cutting machine tools and their accuracy.—S. K.

List of Effective Departmental Standards for Machine Tool Construction and Important Materials, 1948. (Stanki i Instrument, 1948, No. 5, pp. 27–28 ; No. 6, pp. 25–26). [In Russian]. Lists of standard specifications are given for the construction of machine tools, the materials used, the tolerances permitted, lubrication systems, and the design of component parts.—S. K.

Profiling Master Forms for Grinding Cams. V. V. Shvartz. (Stanki i Instrument, 1948, No. 6, pp. 1–5). [In Russian]. Various methods are examined for the graphical-analytical profiling of master forms for cylinder-and-cone grinding machines with oscillatory movement of the shaft and with the master form attached to the shaft.—S. K.

Hard-Faced Forged Tools. V. A. Lapidus. (Stanki i Instrument, 1948, No. 6, pp. 14–16). [In Russian]. An investigation of cutting tools produced by different methods is described ; it showed that a cast tool is inferior to the forged product—S. K.

Machining Austenitic 18/8 Chromium Nickel Steel. M. I. Shitov. (Stanki i Instrument, 1948, No. 6, p. 20). [In Russian]. For the production of cutting tools giving satisfactory performance in the rapid machining of austenitic 18/8 steels when a high quality of surface finish is required, the addition of 2–3% of potassium ferrocyanide to the barium chloride bath is recommended. The hardness of the cutting tool is increased to Rc 64–65·5, resulting in tool life being increased 4–5 times.—S. K.

Equipment for Grinding Spherical Surfaces. A. I. Kryzhanovskii. (Stanki i Instrument, 1948, No. 6, p. 20). [In Russian]. An account is given of an assembly consisting of a grinding wheel together with holding and motivating devices for the production grinding of small spherical surfaces.—S. K.

Rapid Turning of Hardened Steel with Hard Alloy Cutters. V. I. Kapitelman. (Stanki i Instrument, 1948, No. 6, p. 21). [In Russian]. Rapid turning with Pobedit alloy cutters has been successfully used instead of grinding for producing bushes 300 mm. in dia. and 200 mm. long.—S. K.

Transverse Planer Model 7A35. V. V. Shermerevich. (Stanki i Instrument, 1948, No. 6, pp. 26–27). [In Russian]. A description is given of a new rapid universal planer making cuts up to 500 mm. long—S. K.

The Increase of Durability of Cutting Tools by Electric Spark Method. B. Maczewki-Rowinski. (Przeglad Techniczny, 1951, June, pp. 277–280). [In Polish]. The economic importance of the use of the electric spark method for the hardening of cutting tools is demonstrated by data from some Russian factories. A description of the equipment, electrodes, and processes is given.—V. G.

Making 20-Pounder Tank Guns. (Machinery, 1951, vol. 78, June 28, pp. 1063–1076). **Producing the 20-Pounder.** (Machinist, 1951, vol. 94, June 30, pp. 953–960). Reference is made to the operations and equipment employed at the Royal Ordnance Factory, Nottingham, in machining the barrels, for which forgings of Ni–Cr–Mo steel are produced, pierced, rough turned, and heat-treated.—E. C. S.

CLEANING AND PICKLING

The Preparation of Surfaces Before Painting. D. Bermane. (L'Ossature Métallique, 1951, vol. 16, June, pp. 310–314). Methods such as sanding, acid pickling, and flame treatment were investigated by the Belgian Society for Testing Materials for their suitability in preparing sheet iron surfaces for painting. Data obtained in these researches are given and main conclusions are listed.—P. F.

Phosphoric Acid Pickling of Steel. J. Rinse. (Chemisch Weekblad, 1951, vol. 47, May 12, p. 288). [In Dutch]. The addition of inhibitors is not necessary in phosphoric acid pickling but the cost of this acid is considerably higher than that of sulphuric or hydrochloric acid. A middle way has been found by pickling in a sulphuric acid bath followed by a dilute solution of phosphoric acid containing iron to produce the layer of iron phosphate on the steel surface. The Permutit Company's method of ionic exchange treatment of spent phosphoric acid pickle liquor is mentioned.—R. S.

The Use of Inhibitors in Descaling with Acid Solutions. P. Venturini and G. Bianucci. (Calore, 1951, vol. 22, May, pp. 175–179). [In Italian]. A description is given of the authors' experiments on the inhibiting properties of certain organic substances in the corrosion of steel or iron with dilute acid solutions. Suitable mixtures of various inhibitors give better results than can be obtained with the same inhibitors used individually.—M. D. J. B.

Multiple-Flame Torches. (Stanki i Instrument, 1948, No. 5, p. 24). [In Russian]. The oxy-acetylene torch described produces a flame 100 mm. wide ; it is intended for descaling rolled steel and the removal of rust and paint.—S. K.

PROTECTIVE COATINGS

The Influence of Ultrasonics on Electrolytic Processes. A. Roll. (Zeitschrift für Metallkunde, 1950, vol. 41, Oct., pp. 339–343 ; Nov., pp. 413–417 ; 1951, vol. 42, July, pp. 197–201 ; Aug., pp. 238–243). It is shown that the effect of ultrasonic vibrations on the electrolysis of a solution of 40 g. $NiSO_4.7H_2O$ and 35 g. of sodium citrate in one litre of water is equivalent to that attainable by vigorous mechanical stirring of the electrolyte in the vicinity of the electrodes. A progressive decrease in the deposition potential of the metal ions results from a steady increase in the intensity of the ultrasonic vibrations, and the greater current efficiency thus attainable is particularly valuable at high current densities which would under ordinary conditions exceed the saturation current required for maximum ion transport. A study of the movement of small air bubbles under the influence of ultrasonic vibrations in a dilute aqueous solution of glycerine confirmed the hypothesis that the vibration pressure accelerated the hydrogen bubbles appearing with the metal ions at the cathode of the electrolyte in their motion to the surface. Some liquid is carried up with each bubble, and stirring, electrochemically more efficient than that produced by rotating vanes, thus results. The intensity of the ultrasonic vibrations used was 0·3 W./sq. cm. at a frequency of 34 kg. cycles/sec. On the assumption that the momentum imparted to the bubbles was derived from the radiation pressure of the ultrasonic vibrations, the mixing efficiency should be dependent upon the intensity, not upon the frequency. However, tests carried out at 560, 34, 15, and 0·1 kg. cycles/sec. showed a fall of the stirring efficiency with increasing frequency. This was qualitatively explained in terms of the characteristics of the apparatus, but not rigorously confirmed by experiment. Work repeated on silver and copper electrolytes gave results similar to those obtained with nickel solutions.

Under ordinary conditions bright deposits of nickel are obtained on polished brass at current densities of 2·7 m. amp./sq. cm. at 20° C. with the electrolyte of the composition given above. At higher or lower densities surface deposits tend to be mat. Under the influence of an ultrasonic beam directed parallel to the electrode surface, vertically through the solution, bright deposits were obtained at 40 m. amp./sq. cm. with an ultrasonic field intensity of 0·3 W./sq. cm. The explanation is advanced that the metal ions acquire an oscillating component of motion from the supersonic field, which is superimposed upon the normal drift velocity. In consequence, the ions impinge at angles other than 90° upon the cathode surface.—P. F.

Designation of Metallic Surfaces. Part I. H. Thielsch and G. Stroman. (Metal Finishing, 1950, vol. 48, Sept., pp. 66–70). The indexes used to describe the geometrical characteristics of a metal surface are discussed. These include lay, surface roughness (average or root mean square) maximum height, average height of profile, average depth of hollows, roughness width, and ' waviness ' height and width.—J. P.

Additive Compounds in Electroplating Baths. Part III. M. Rubinstein. (Metal Finishing, 1950, vol. 48, Nov., pp. 68–74). Continuation of a series of articles (*see* Journ. I. and S.I., 1951, vol. 167, Feb., p. 227). The mode of action and application of wetting agents in plating baths is discussed. The addition of salts to act as buffers, to increase conductivity, throwing power, and current efficiency, or to sequester undesirable bath contaminants is also dealt with.—J. P.

Mechanism and Kinetics of the Chromizing of Mild Steel in Atmospheres Containing Chromous Chloride. T. P. Hoar and E. A. G. Croom. (Journal of The Iron and Steel Institute, 1951, vol. 169, Oct., pp. 101–109). It is shown experimentally that 0·1% C mild steel exposed to atmospheres containing

chromous chloride at 950–1100° C. becomes coated with a chromium-rich layer, owing to the reactions $CrCl_2 + Fe \rightarrow Cr + FeCl_2$ and, if the atmosphere contains hydrogen, $CrCl_2 + H_2 \rightarrow Cr + 2HCl$. The latter reaction proceeds catalytically on the growing surface. The overall rate of chromizing is limited, in the early stages, by the rates of the reactions (both of which are increased by increase of partial pressure of chromous chloride) and, in the later stages, by the rate of metallic interdiffusion in the growing alloy layer; the overall rate is at first constant, and later falls off parabolically, with time. The apparent energy of activation of the diffusion process is 57 kg. cal. Various practical chromizing processes are discussed in the light of the experimental results.

Elements of Cost in Chromium-Plating. M. de Buyer. (Revue Générale de Mécanique, 1951, vol. 35, July, p. 215). Some factors affecting cost assessments including type of surface, weight of part, and degree of surface finish are mentioned.—R. S.

Present Possibilities of Inspecting Chromium-Plated Parts. M. Morisset. (Revue Générale de Mécanique, 1951, vol. 35, July, pp. 214–215). Photoelectric methods of measuring porosity, and microhardness and wear, and adhesion tests for chromium-plating are briefly described.—R. S.

Chromium-Plated Segments of Diesel Engines on the French State Railways. M. Olive. (Revue Générale de Méchanique, 1951, vol. 35, July, pp. 213–214). Wear tests on chromium-plated cylinder linings and segments after 100,000 km. are summarized.—R. S.

Metal Windows: Large Scale Plant in Scotland. (Iron and Steel, 1951, vol. 24, July, pp. 331–333). At the new Cadzow works of Macleans (Metal Windows) Ltd., metal doors and windows are manufactured to British Standard Specification B.S. 990 : 1945, and also to special designs. This article briefly describes the building, zinc-plating, and painting of the frames; recovery of sulphate from the pickle solution is also mentioned. The plating and painting processes are automatic. The electro-galvanizing plant is probably the largest of its type in the world.—G. F.

Galvanizing Characteristics. R. W. Sandelin. (Hot Dip Galvanizers' Association: American Foundryman, 1950, vol. 18, Dec., pp. 64–67). A study and comparison of galvanizing characteristics of malleable and grey cast irons and some steels are reported. Coating properties evaluated were: (1) Appearance; (2) thickness; (3) weight; and (4) weight loss of test samples by immersion in zinc at 850° F.—E. J. D. S.

Effect of Bath Composition of Aluminium Coatings on Steel. D. O. Gittings, D. H. Rowland, and J. O. Mack. (Transactions of the American Society for Metals, 1951, vol. 43, pp. 587–610). Various elements were added to hot-dip aluminium coating baths. Only silicon, copper, and beryllium decreased the thickness of the alloy layer more than 50%, but coatings with copper and some other elements spoilt the surface finish. Beryllium was more effective than silicon in improving the behaviour of the coated steel in the flat-bend test.—E. T. L.

Polish-Made Metal Spraying Gun GPM.L.2. J. Lapinski. (Przeglad Techniczny, 1951, May, pp. 226–229). [In Polish]. This gun is described and illustrated.—V. G.

Subsidiary Paint Tests at Birmingham: Final Report. J. C. Hudson. (Journal of The Iron and Steel Institute, 1951, vol. 169, Oct., pp. 153–156). An exposure test over 15 years has confirmed that surface preparation is the most important single factor contributing to successful protection of iron and steel, by means of paint, against atmospheric corrosion. The average life of 2-coat painting schemes was nearly six times greater on a pickled surface than on a weathered and wire-brushed one. The best of the painting schemes tested—two coats of micaceous iron ore paint—protected pickled wrought iron perfectly for the whole of the 15 years; even better results should be obtained by using a red lead priming paint under a finishing coat of micaceous iron ore paint. Heating a weathered surface, so as to dehydrate the rust, improved the performance of painting schemes but this was still greatly inferior to that on the descaled and unrusted surface obtained by pickling.

Enameller's Viewpoint of Design. T. J. MacArthur. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1951, vol. 91, July 5, pp. 22–24, 26). The cost of scrapping articles in the enamelling shop emphasizes the importance of careful design in the cast-iron and sheet-steel articles awaiting enamelling.—J. E. W.

Styling of Enamelled Products. A. B. Kirkbride. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1951, vol. 91, July 5, pp. 17–18). The functions of the sales manager, the development engineer, the production engineer and the industrial design expert, and the co-operation between them are outlined.—J. E. W.

Enamelling of Sheets and Castings. S. Herbst. (Elektrowärme Technik, 1950, vol. 1, No. 5–6, pp. 146–149). A survey of the development of electric furnaces employed in enamelling steel sheets and castings is given.—P. F.

Application of Vinylic Resins in the Industry of Paints for Building. M. Chevassus. (Peintures, Pigments, Vernis, 1951, vol. 27, Sept., pp. 545–548). These resins give paints exceptional anti-corrosion qualities. To obtain good adherence to metals, including steels and ferrous metals, a 'wash primer' must first be applied to bring about passivation of the metal surface.—T. E. D.

A Method of Examining the Adhesion of Paint to Steel. S. C. Britton and R. M. Angles. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 358–363). A strip of cellulose adhesive tape, which has been pressed firmly on a painted surface, carries with it, when it is removed by a snatch-pull, areas of paint that have poor adhesion. A reproducible method based on this fact has been developed to compare paints and methods of preparing steel for painting, by revealing the area of paint loosened by corrosion or by controlled physical damage. Manufacturing operations on coated tinplate have been represented by a cupping test, and the damage suffered by paint coatings in service is represented by parallel scratches made mechanically, and by the impact of a falling weight. In corrosion tests, the method is very suitable for use after the provisional standard sea-water spray test. Results show the improved paint adhesion obtained by phosphating or tin-plating before painting.

POWDER METALLURGY

Contribution to the Theory and Practice of the Pressing of Powdered Materials. C. Ballhausen. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 185–196). Marked differences occur in the apparent density of pressings made from powdered materials. These are to be attributed to varying pressure distribution and direction. The laws governing this distribution, actually caused by wall friction, have been derived. The equation so formulated is similar to that for the friction between a rope and a pulley. The accuracy of the equation has been tested and its applicability demonstrated by measurements on rubber, lead, iron, and copper. A new relationship between pressing load and amount of compacting has also been established.—J. P.

The Physics of Sintering. H. G. Crone and J. H. McKee. (British Coal Utilisation Research Association, Monthly Bulletin, 1950, vol. 14, Sept., Review Series No. 95, pp. 329–240). The literature on sintering in powder-metallurgy processes is reviewed. There are 66 references.—R. A. R.

Ceramics and Metals. M. Lepingle. (Silicates Industriels, 1950, vol. 15, No. 3, pp. 53–54). The possibilities of improving the heat-resisting properties of metals by means of ceramics are briefly surveyed. They include enamelling, pressing or fusing the refractory oxides into the metal, and sintering of the mixed metal and refractory powders.—N. McE.

Fundamental Problems of Sintering Processes. W. E. Kingston and G. F. Hüttig. (The Physics of Powder Metallurgy: Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 1–24). Valuable scientific approaches are based on thermodynamics, mechanisms of atom transport, and studies of sintering kinetics: these introduce the consideration of free-energy changes (as applied to systems with high surface area, lattice faults, and forced conditions due to mechanical work), work required to dissolve or establish atomic bonding, the energy relationships of self-diffusion, various cases of atomic transport, the effects of pressing, particle size and particle size distribution on nucleation, and temperature effects. Many results are available for the region of final densification and elimination of voids, but greater understanding of the sintering processes should follow from studies of the prior ranges of 'adhesion' where certain basic processes are originated. Suggestions for future work are made.—K. E. J.

Self-Diffusion in Iron. F. S. Buffington, I. D. Bakalar, and M. Cohen. (The Physics of Powder Metallurgy: Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp.

92–107). Studies of self-diffusion may be made using specimens of the metal containing radioactive isotopes, in close contact with inert specimens. The test pieces are arranged as co-axial cylinders or as active layers deposited on inert blocks. The progress of diffusion is measured by determining the activity of successive layers removed by machining or (where diffusion is slow) measuring the decrease of surface activity. Experimental details are given of surface-decrease determinations on iron at various temperatures and self-diffusion coefficients for α- and γ-iron are presented. These values are consistent with previously determined activation energies of molybdenum, manganese, and nickel diffusing in iron, and with corresponding coefficients for silver, copper, lead, and gold.—K. E. J.

Surface Tension as a Motivation for Sintering. C. Herring. (The Physics of Powder Metallurgy : Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 143–178). The lowering of free energy during sintering may be motivated by pressure or surface tension ; the latter is more important except in the initial stages and during hot pressing. Transport of material may occur by plastic or viscous flow, evaporation and condensation, volume diffusion, and surface migration. A theory is presented for the effects of surface tension on these mechanisms. The relations between surface tension and stress, and surface stresses and dislocations and plastic flow, are discussed. In the absence of surface stresses, the contribution of plastic flow within the crystals to the sintering of pure substances is probably negligible.—K. E. J.

Sintering with a Liquid Phase. F. V. Lenel. (The Physics of Powder Metallurgy : Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 238–253). The 'heavy alloy mechanism' occurs when two or more metal powders, possessing some mutual solubility, are sintered at a temperature between the solidus and liquidus of the alloy system. The resulting structure shows regular-shaped particles of the solid constituent embedded in a matrix of the liquid constituent, and solid particle growth occurs, together with densification which rapidly reaches the absolute limit. Details are given of tests on 80/20 Fe–Cu mixtures sintered at above 1094° C. Effects due to variations in particle size, methods of preparation of the powders, and sintering time are discussed. A striking observation is the linear relationship between the densification parameter and the logarithm of the sintering time.—K. E. J.

Principles and Present Status of Hot Pressing. C. G. Goetzel. (The Physics of Powder Metallurgy : Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 256–276). Hot pressing of metal powders is only used on a limited scale in industry, although the technique is capable of achieving complete densification, eliminating sintering, close size control, working from less costly raw materials, and improving physical properties beyond values obtainable by cold-pressing techniques. Results so far obtained with copper, gold, brasses, bronzes, iron, steels, and cemented carbides are surveyed in some detail. Extended use of the technique depends on the development of machinery which can overcome the problems of heating the die and compact. Materials and other factors are enumerated.—K. E. J.

Electrical Properties as Indicators of the Degree of Sintering. H. H. Hausner and J. H. Dedrick. (The Physics of Powder Metallurgy : Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 320–340). Measurements of electrical properties of sintered materials show several advantages compared with other measurements. They can be made with simple equipment, and are excellent indicators of changes of bonding, being particularly sensitive in the earlier stages of sintering. Nevertheless, such methods have been very seldom used. Correlations between electrical resistivity and its temperature coefficient, and pressure, density, and layer effects are examined. The analysis of the results depends on treating the compact as a network of electrical resistances. It is concluded that such differences as those between sintering *in vacuo* and in various atmospheres can be easily observed by resistivity studies.—K. E. J.

Alloy Powder Products from Fully Alloyed Powders. G. J. Comstock and J. D. Shaw. (The Physics of Powder Metallurgy : Sylvania Electric Products Inc. Symposium, Aug. 24–26, 1949, pp. 372–386). It now appears that any alloys which can be melted, can be disintegrated (*e.g.*, by mechanical, gaseous, or liquid methods) into powder form. Hot- and cold-pressing techniques are being studied for ferrous alloy powders. Cold pressing, sintering, and heat-treating steel powders, with or without coining or other variations, will produce end products with properties suitable for commercial use. Research work has evolved a process of pressing, sintering, and hot coining of alloy steel powders which indicates the possibility of reproducing the normal physical characteristics of plain carbon and alloy steels : a similar technique shows promise for heat-resistant alloys such as those used for turbine parts.—K. E. J.

Some Relations of Powder Characteristics to the Elastic Modulus and Shrinkage of Sintered Ferrous Compacts. G. D. McAdam. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 346–358). Elastic properties and shrinkage in sintered ferrous alloys, including sintered steels containing manganese and nickel, were studied comprehensively in relation to the properties of the various iron powders, attention being directed mainly to an alloy of the nominal composition : 90% iron—8% copper—2% graphite. Powders were distinguished in terms of particle dimensions, size distribution, surface shape, density, and moulding characteristics. A detailed description of special apparatus and general test procedure is given, also an account of the method of preparing briquettes under reproducible conditions of mixing, compression, and heat-treatment. Test results showed that the elasticity E_n expressed as a fraction of Young's modulus E of steel varied with the porosity ϵ in a predictable manner, defined by the expression : $E_n/E = (1 - \epsilon)^{3 \cdot 4}$, applicable to sintered steels and probably more generally to certain cast and heat-treated graphitic materials. An empirical equation was derived from which it was possible to predetermine the linear contraction of the standard iron–copper–carbon alloys at 1100° C. in terms of the packing, green, and theoretical densities, and the particle size. The approximate elastic moduli of these alloys were deduced from the shape and compression characteristics of powder particles. From these expressions a tentative equation was derived involving a term in particle shape, showing the influence of density measurements, made before heat-treatment, on the sintered density.

Heat- and Corrosion-Resistant Sintered Materials. R. Kieffer and F. Benesovsky. (Zeitschrift für Metallkunde, 1951, vol. 42, Apr., pp. 97–106). A survey of methods of producing heat- and corrosion-resistant materials for use at very high temperatures is presented. The creep and oxidation resistance of alloys produced from the melt, of sintered compounds of the TiC–Co type and of ceramic materials is discussed. The scope and properties of refractories, like alumina–silica mixtures, for surface coating of sintered metals of high melting points such as tungsten and molybdenum, which, unprotected, oxidize at comparatively low temperature, are considered. The authors explain why they believe that little progress in improving heat and oxidation resistance of metal alloys produced from the melt is to be expected, though greater advances in this field are likely to come from sinter technique. Eighty-five references are given.—P. F.

The Investigation of the Processes of Pressing and Sintering of Metal Powders by the Electrical Conductivity Method. V. I. Likhtman and L. T. Nazarov. (Doklady Akademii Nauk, U.S.S.R., 1951, vol. 78, No. 4, pp. 749–752). [In Russian]. The investigation of the formation of contact surfaces in the processes of pressing and sintering of metal powders with and without the presence of active and inactive lubricants is described.—V. G.

PROPERTIES AND TESTS

Tensile and Impact Properties of Iron and Some Iron Alloys of High Purity. W. P. Rees, B. E. Hopkins, and H. R. Tipler. (Journal of The Iron and Steel Institute, 1951, vol. 169, Oct., pp. 157–168). The tensile and impact properties of high-purity iron and of iron–manganese, iron–carbon, and iron–carbon–manganese alloys, at various temperatures covering the tough to brittle transition, are discussed. The technique used to carry out tests at low temperatures is described. Attention is drawn to the two types of brittleness, intergranular and cleavage, that can occur in iron. The evidence presented indicates that oxygen is effective in promoting intergranular brittleness. The oxygen content below which intergranular brittleness is not encountered is less when the iron is made in one furnace than in another. The incidence of intergranular brittleness is also affected either by grain size or by some other factor resulting from the treatment used to obtain

coarse grains, *i.e.*, straining and heating below the transformation temperature. Manganese and carbon plus manganese, are shown to lower the temperature of transition from tough to brittle fracture, and to raise the cleavage strength. The effect of carbon in raising the transition temperature may possibly be explained by the rise in yield stress.

Some Observations on Steel Subject to Static Pure Bending. R. Böklen. (Zeitschrift für Metallkunde, 1951, vol. 42, June, pp. 170–174). X-ray and mechanical strain measurements and observations of the onset of yielding and the formation of the first flow lines were made on flat annealed steel bars subject to bending. The yield strength in compression was found to be higher than the yield strength in tension in a plain carbon steel, but not in the Cr–Mo steel investigated. This is ascribed to the notch effect of inclusions in the plain carbon steel, and entails the predominance of internal compressive strains over tensile strains after unloading. In the carbon steel, strain figures appeared on the compression side at stresses almost 20% higher than those inducing strain figures on the tension side. In the alloy steel such an anisotropy was not observed, but the character and direction of the strain figures were found to be essentially different on the tension and compression sides.—P. F.

Contribution to the Study of the Variation of Notch Toughness in Relation to Testing Temperature. G. Remy and J. M. Vialle. (Documentation Métallurgique, 1951, vol. 48, Jan.–Mar., pp. 3–60). After discussing the influence of sharpness and depth of notch, width of test piece, testing temperature, and velocity of impact on notch toughness and on the notch-toughness/temperature curve, the relationship between microstructure and the position of the transition zone is examined. The results of tests showed the influence on the notch-toughness/temperature curve of the direction from which the specimen is taken, and the effects of temper brittleness and of lead additions. In the case of 18/8 steels the effect of sensitization is examined. The authors conclude that: (1) The transition temperature from the tough to the brittle state is practically the same for longitudinal and transverse specimens; (2) mass effect tends to displace the curve, such displacement varying with the hardenability of the steel; (3) sensitization of 18/8 steels has an analagous effect; and (4) increasing additions of lead have practically no effect on the transition zone but, like additions of sulphur, cause a general and uniform lowering of the notch toughness.—R. S.

Evaluating Carbon Plate Steels by the Keyhole Charpy Impact Test. R. W. Vanderbeck. (Welding Journal, 1951, vol. 30, Jan., pp. 59s–64s). The keyhole Charpy impact test was used to obtain data on the effect of composition, deoxidation practice, and plate thickness on the transition temperature of carbon steels. Lowering the testing temperature resulted in a sharp transition from tough to brittle behaviour. In the observed transition range both high and low impact values were obtained. The absence of values at intermediate energy levels was demonstrated by frequency distribution plots. Low transition temperatures are favoured by deoxidation with silicon and aluminium, by low carbon and manganese contents and by thinner plates.—U. E.

Direct Explosion Test to Evaluate Load-Carrying Capacity of Welded Steel Structures. G. S. Mikhalapov. (American Society for Testing Materials, Bulletin, 1951, Feb., pp. 53–64). Failure of pressure vessels, ships, and many other structures can be attributed in many cases to poor ductility of structural materials under certain conditions of test. The test described here can be used for the evaluation of performance of homogeneous and non-homogeneous materials when subjected to (*a*) high rate of loading, obtained by means of a direct explosion method, and (*b*) the combined effect of triaxial tension, such as that found at notches. When subjected to the test, various types and grades of 1-in. steel plate exhibited: (1) A range of performance which, in general, correlated with notch-impact properties; and (2) a wide difference of performance, particularly at low temperatures, between welded and unwelded plates of otherwise identical composition and properties. The test shows a high degree of correlation with results of static loading to destruction on full-scale model sections of ship decks.—T. E. D.

The Determination of Impact Strength on Aged Specimens with Impressed Notches. A. Krüger. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 171–176). Resistance to ageing of steels is usually determined by an impact test on a specimen which has been cold worked 10%, by compression or extension, artificially aged, ground to size, and notched. For routine use, performing the deformation and producing the notch in one operation, viz., by cold-pressing a 3-mm. deep notch, root radius 1 mm., into a standard test piece, saves much labour, accurate machining, and time. The results are in good agreement with those by the normal DVM procedure for unalloyed low-carbon steels but the discrepancy is too great with high-carbon steel. It is possible to use the impressed notch for normalized steels, if the notch is made before the normalizing.—J. P.

Preliminary Trials with a Notched-Bar Ageing Test Piece with an Impressed Notch. W. Dick. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 161–170). A new form of specimen has been developed in trials designed to replace the usual DVM surface-compressed, aged impact test-piece with machined notch. It has an impressed notch and its main advantage is the ease with which it may be prepared. The formation of the notch produces the necessary compression of the sample. The effect of variations in shape and preparation in tests of the resistance to ageing of mild steel is discussed. The results on a test piece with a wedge-shaped notch, 3 mm. deep, with the burr removed, showed no quantitative correlation with those on DVM specimens. Marked differences were attributed to the fact that, with an impressed notch, steel exhibits a more exaggerated response to artificial ageing treatment.—J. P.

Statistical Analysis of Tests of Charpy V-Notch and Keyhole Bars. J. A. Rinebolt and W. J. Harris, jun. (Welding Journal, 1951, vol. 30, Apr., pp. 202s–208s). In plotting the energy expended in impact tests against the testing temperature and drawing a transition temperature curve for shear to cleavage fracture the scatter depends on the control of notch contour, specimen dimensions, and metallurgical characteristics. Test data are studied statistically and it is shown that the energy values determined with the keyhole specimens are more reproducible than for **V**-notch specimens.—R. A. R.

Higher Design Stresses for Pressure Vessels. P. R. Cassidy. (Welding Journal, 1951, vol. 30, Mar., pp. 123s–124s). The effect of stress concentration in pressure vessels under conditions of multiaxial stress and for endurance limits up to 100,000 cycles is discussed.—U. E.

Stress Relieving and Fracture Strength. D. Swan, A. R. Lytle, and C. R. McKinsey. (Welding Journal, 1951, vol. 30, Mar., pp. 135s–145s). The effects of straining and heating involved in the application of the controlled low-temperature stress-relieving process on transition temperature have been studied, and no appreciable metallurgical effect was found. It is suggested that residual stresses may be quite important in the failure of welded structures under conditions which inhibit plastic flow. The amount of plastic deformation occurring during a destructive test, as measured by the amount of strain hardening which takes place at the initiation of fracture depends on the testing conditions.—U. E.

Spherical Shells Subjected to Internal Pressure and Low Temperatures. J. L. Walmsley. (Welding Journal, 1951, vol. 30, Mar., pp. 153s–167s). Results are reported of a series of tests in which spherical shell specimens were subjected to internal pressure up to rupture at sub-normal temperatures. Under biaxial tensile stress at room temperature and down to −40° F. the semi-killed steels (0·2% C) retained about the same capacity for deformation and energy absorption as under conditions of uniaxial tensile stress. The transition temperature associated with a 'pure' biaxial state of stress apparently lies at subzero temperature. With 100% joint efficiency and good ductility the shell tested at room temperature developed a nominal ultimate strength of about 87% of the nominal tensile strength of the material.—U. E.

The Effect of Strain-Hardening on the Equalization of Moments in the Simple Plastic Theory. M. R. Horne. (Transactions of the Institute of Welding, 1951, vol. 5, Feb., pp. 147*r*–153*r*). The behaviour of rigid frame structures under loading has been investigated. It is shown that the extent to which the equalization of moments predicted by the simple plastic theory can take place depends upon the nature of the steel and the disposition of the loads. Equalization of moments takes place more readily if yield first occurs in a region which at collapse is subjected to a uniform bending moment. The simple plastic theory can be applied to mild-steel structures because it gives a reasonable estimate of the loads at which deflections start to increase rapidly, and of the bending moment distributions under such loads.—U. E.

The Determination of Initial Stresses and Results of Tests on Steel Plates. Part I. The General Problem and Evaluation of the Method Used. E. W. Suppiger. (Welding Journal, 1951, vol. 30, Feb., pp. 91s–93s). Part I gives an introduction to the problem and an outline and evaluation of the hole method using an electric resistance strain gauge.—U. E.

The Determination of Initial Stresses and Results of Tests on Steel Plates. Part II—The Method of the Hole. C. Riparbelli. (Welding Journal, 1951, vol. 30, Feb., pp. 93s–97s). A mathematical treatment is presented for the determination of stresses and strains in plates with and without small circular holes subjected to biaxial tension or compression.—U. E.

The Determination of Initial Stresses and Results of Tests on Steel Plates. Part III—Experimental Techniques and Test Results. E. R. Ward. (Welding Journal, 1951, vol. 30, Feb., pp. 97s–104s). Several testing techniques and methods of calculation for evaluating coefficients of sensitivity for tensile stress are described. Calibration and field-type tests are explained and results obtained by the hole method using experimental coefficients are discussed.—U. E.

Cohesion and Plasticity of Metals. F. Mazzoleni. (Rivista di Meccanica, 1951, vol. 2, May 10, pp. 11–15). [In Italian]. A theory of the mechanical resistance of metals is developed based on their capacity to resist plastic deformation without failure. From nuclear considerations it is shown how high resistance in a metal can be traced to the high plasticity of the individual grains which contribute to the strength of the whole metal structure.—M. D. J. B.

Measurement of the Curvature of Stress Trajectories in Photoelastic Models. A. F. C. Brown. (British Journal of Applied Physics, 1951, vol. 2, May, pp. 138–140). The use of Jessop's extension of the Lamé-Maxwell equations for separating the principal stresses in a three-dimensional photoelastic problem depends for its accuracy on a precise knowledge of the curvature of the stress trajectories crossing the line along which the integration process is carried out. In this short note the author describes a method of measuring these curvatures very accurately.—J. A. L.

Low-Temperature Fractures in Tempered Alloy Steels. A. R. Entwisle. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 36–38). Low-alloy steels susceptible to temper-embrittlement may show fracture at low temperatures with either a cleavage or an intergranular fracture, depending on the heat-treatment. The cleavage type of failure is shown to be related to the original martensite structure produced on quenching. Under certain conditions both types of failure can occur in the same fracture. Plain carbon steels similarly heat-treated show cleavage but not intergranular fracture. In an appendix P. B. Hirsch explains the interpretation of the Debye-Scherrer rings.

Processes Occurring in a Metal Subject to Tensile and Oscillating Stresses. C. Petersen. (Zeitschrift für Metallkunde, 1951, vol. 42, June, pp. 161–170). From R. B. Heywood's formula relating the stress gradients in smooth and notched specimens to their fatigue strength a new, simpler expression is derived. It covers experimental results more adequately than any of the other formulæ previously proposed. M. D. Morkovin's and H. F. Moore's theory of the equivalent notch is further developed, and it is shown that R. B. Heywood's expression can be derived from the modified result. The domain of validity of the formulæ is discussed and the manner of applying them in practice is described.—P. F.

Results of X-Ray Experiments on the Dependence of the Fatigue Limit on the Yield Strength. A. Schaal. (Zeitschrift für Metallkunde, 1951, vol. 42, May, pp. 147–154). Changes in the surface stresses of polished specimens of a number of plain carbon steels and of alloy and low-alloy structural steels were observed, during fatigue tests, by means of Laue back-reflection X-ray photographs. Body stresses induced by the mechanical treatment of the specimens, which are generally compressive, and decrease from the surface towards the centre of the specimens, begin to fall on applying bending fatigue stresses. The rate of decrease is greater the lower the static yield stress of the metal. In the case of high-tensile steels a decrease in these stresses is observed only when the fatigue limit is exceeded. It was found that the ratio σ_E/σ_E' and the ratio σ_{wb}/σ_s, (where σ_E is the residual surface stress before fatiguing, σ_E' the residual surface stress at the fatigue limit, σ_{wb} the fatigue limit, and σ_s the yield (0·2% proof) stress varied in the same manner with the yield stress.—P. F.

Fatigue Tests of Beams in Flexure. (Welding Journal, 1951, vol. 30, Mar., pp. 105s–115s). Results are given of fatigue tests on various types of beam similar to those used in actual structures. The carrying capacity of a rolled beam is considerably higher than that of a fabricated beam of equivalent section modulus. The use of cover plates on rolled beams will increase the capacity. The stress-raising effect of welding across the ends of partial length cover plates is about the same as that of the longitudinal welds along the edges of the cover plates.—U. E.

Experiments for the Determination of the Influence of Residual Stresses on the Fatigue Strength of Structures. M. Roš. (Transactions of the Institute of Welding, 1950, vol. 13, Oct., pp. 83*r*–93*r*). Special specimens with (*a*) a drilled hole 10 mm. in dia., (*b*) the hole filled with a loose plug, (*c*) the hole filled with a plug shrunk in, (*d*) with a conical dowel pressed in, (*e*) a 20-mm. hole enlarged by pressing, (*f*) welded-in plugs, and (*g*) with a weld bead deposited on one edge, were fatigue tested to study the effect of the residual stresses set up in each case. In general, the residual stresses had no effect on the fatigue strength, but any small faults in welding did result in an important decrease in fatigue strength.—R. A. R.

Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25° C. and −196° C. J. W. Spretnak, M. C. Fontana, and H. E. Brooks. (Transactions of the American Society for Metals, 1951, vol. 43, pp. 547–570). Tests were made on aluminium alloys, and various steels showing that the notch increases the strength in tension, but decreases the fracture strength and the tensile reduction of area. In the unnotched tensile tests the modulus of elasticity, yield strength, ultimate strength, and nominal fracture stress all increase with decreasing temperature.—E. T. L.

Concerning the Fatigue of Metals. N. S. Akulov, I. P. Mazin, and Ya. I. Fel'dshtein. (Doklady Akademii Nauk U.S.S.R., 1951, vol. 78, No. 2, pp. 263–266). [In Russian]. On the basis of a simple physical model of the formation of primary fatigue cracks a relationship between the amplitude of alternating stress A and the number of cycles N was developed.—V. G.

Fatigue Tests on Molybdenum, Chromium–Molybdenum, and Chromium–Molybdenum–Vanadium Steels. E. Theis. (Stahl und Eisen, 1951, vol. 71, June 7, pp. 619–624). The yield point, tensile strength, elongation, reduction in area and the notched bar impact strength at room temperature and at 500° C. were determined on Mo, Cr–Mo, and Cr–Mo–V steels, heat-treated to give different tensile strengths. The creep limit and the fatigue strength at 500° C. were measured on smooth and notched specimens. The raising of the tensile strength at room temperature by suitable heat-treatment produced a corresponding increase in the creep limit; the increase was only slight in the 10,000-hr. fatigue strength and, by extrapolation, almost completely disappeared in the 100,000-hr. fatigue test. The fatigue strength of a steel is thus essentially controlled by its alloying elements, and only to a small extent by the usual heat-treatments given to improve room temperature tensile strength. The usual heat-treatment for raising tensile strength and creep limit is not only ineffective in raising the fatigue strength, the results indicate that it is detrimental since it increases the tendency to embrittlement in long-time tests.—J. P.

Effect of Hardness on Temper Brittleness. D. C. Buffum and L. D. Jaffe. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1951, vol. 3, July, p. 540; Journal of Metals, 1951, July). The author presents the results of a study of the combined effects of hardness and temper brittleness on the transition temperature in a commercial SAE 3140 steel, the hardness range considered being 24½–32½ Rockwell C. The difference between transition temperatures for the embrittled and unembrittled conditions is constant at any given hardness, the temperatures increasing in a parallel fashion as the hardness increases.—G. F.

Precision Measurement of Rockwell Hardness Diamond Penetrators. F. R. Tolmon and Jill G. Wood. (Engineering, 1951, vol. 172, July 20, pp. 89–90). The authors describe methods used at the National Physical Laboratory for measuring diamond penetrators, the measurements required being the angle of the core and the radius of the point. These make use of light interference patterns, and measures to an accuracy of ± 1 min. of arc. For the critical inspection of the accuracy of form of the penetrator at its extreme tip a Zeiss Linnik interference microscope is used, capable of giving

a visual magnification of 600 diameters ; this is fitted with a photographic attachment enabling a permanent record to be made at half this magnification.—M. D. J. B.

Dynamometer for Testing Mechanical Loading Unit in Micro-Hardness Tests. E. S. Berkovich. (Zavodskaya Laboratoriya, 1951, vol. 16, No. 3, pp. 381–382 : Industrial Diamond Review, 1951, vol. 11, July, p. 158). The use of a dynamometer for checking the accuracy of the loading mechanism of a microhardness tester PMT-2 for loads of 1 to 200 g., is described.—T. E. D.

Analysis of the Rockwell Hardness Test, Employing a New Deadweight Testing Machine. C. E. Phillips and A. J. Fenner. (National Physical Laboratory : Engineering, 1951, vol. 172, July 13, pp. 57–61). The introduction of Rockwell hardness tolerances into specifications has drawn attention to discrepancies between results obtained from different testing machines. This investigation was undertaken to assess the reasons for such differences. It was found that many of the conical diamond indenters produced and employed in industry do not conform to tolerance ; that the hardness number is a function of the profile of the spherical tip of the indenter ; that there is no clear indication that small departures from the nominal included angle have any influence on the hardness number ; that errors in the applied loads have an important effect on the hardness number, and lastly that creep plays an important part if testing exceeds 15 min. duration.—M. D. J. B.

Metal Transfer from Piston Rings to Cylinders during "Run-In". C. D. Strang and J. T. Burwell. (Institution of Mechanical Engineers, Automobile Division, 1949–50, Proceedings, Part IV, pp. 169–175). Piston rings with radioactive wearing surfaces were used to study the microwelding between rings and cylinder wall during 'run-in' in a small, water-cooled, internal combustion engine. The results indicated that microwelding and the accompanying transfer of metal were present under the mildest conditions of engine operation, including motoring with the engine cylinder-head removed. The distribution of microwelding along the ring travel was found to correspond to the wear profile observed in engine cylinders by other workers. Such transferred material may play a part in the formation of the glazed layer which is said to be present on 'run-in' cylinder walls and rings. The presence of transferred metal at all points along the ring travel indicates that the piston ring was not fully supported by a hydrodynamic oil film of sufficient thickness to separate completely the surfaces of the ring and the cylinder wall.

Properties Influencing Wear of Metals. T. L. Oberle. (Journal of Metals, 1951, vol. 3, June, pp. 438–439G). The author discusses the factors influencing the wear of metals and describes methods of reducing or eliminating the resulting loss, which is even greater than that due to corrosion. The ratio of hardness to elastic modulus should replace the hardness value as an index of the surface stability of wear-resisting materials, the improvement of which could be accelerated by the development of a simple indentation test for measuring the elastic modulus of surfaces.—G. F.

The Performance and Stability of Permanent Magnets. A. G. Tyrrell. (Journal of the British Institution of Radio Engineers, 1950, vol. 10, May, pp. 182–191). B/H curves are given for cobalt (3–35%), Alnico, Alcomax, Reco, and Ticonal (8% Al, 14% Ni, 3% Cu, 24% Co) magnets, also a table of magnetic properties and compositions of 57 alloy magnets of British or American manufacture. Effects on drift of vibration, temperature, stray fields, and time are discussed. Methods are given for stabilizing magnets, and a table presented showing the degree of reduction of magnetic performance necessary to produce maximum stability for tungsten steel, chromium steel, cobalt, Alnico, and Ticonal magnets. The latest developments in permanent magnet alloys are discussed.—E. W. V.

Single Crystal Magnetostriction Constants of an Iron–Cobalt Alloy. J. E. Goldman. (Physical Review, 1950, vol. 80, Second Series, Oct. 15, pp. 301–302). The results of magnetostriction measurements on a very small single crystal of a 30% cobalt–70% iron alloy are reported. A resistance strain gauge technique was used, specially adapted for measurements on very small single crystals. Using Becker's notation, the authors obtained : $\lambda_{[100]} = 1{\cdot}5 \times 10^{-5}$, $\lambda_{[111]} = 8{\cdot}5 \times 10^{-5}$ for the magnetostriction in the principal crystal directions.—C. J. B. F.

The Electrical Resistance of Heaters of Iron-Chromium-Aluminium Alloy. H. Thomas. (Zeitschrift für Metallkunde, 1950, vol. 41, Jan., pp. 185–190). The electrical resistances at 20° C., and their thermal coefficients, of Fe–Cr–Al alloys, containing up to 10 atomic-% Cr and 28 atomic-% Al, were measured. The curves run parallel to the iron corner of the ternary diagram. By recording the resistances photographically it was possible to detect the slight decrease in resistance when the α–γ transformation took place. The resistance was increased by cold working only if the aluminium content was less than 6%. It was also increased by heat-treatment at mild temperatures, though sometimes approaching the limit very slowly. After quenching from above 500° C. the resistance was independent of the quenching temperature. Some alloys high in aluminium gave an abnormally high increase in resistance, after either tempering or quenching, depending very much on the aluminium content but not at all on the chromium.—N. McE.

The Influence of Cold Work upon the Electrical Resistance of Iron–Chromium–Aluminium Alloys. A. Schulze. (Zeitschrift für Metallkunde, 1951, vol. 42, Apr., pp. 120–122). The influence of cold work upon the electrical resistance of iron–chromium–aluminium alloys Megapyr I, Megapyr II, Kanthal A 1, and Ferropyr I, which are used for heating elements, was investigated. An increase in the resistivity was found to accompany annealing and a lowering of the resistivity occurred on cold working. The maximum increase was reached on ageing at about 300° C. Compared with the resistance changes taking place in most other metals on cold working and annealing, the behaviour of the alloys investigated was highly anomalous.—P. F.

Non-Destructive Testing of Steels. M. de Courcel. (Documentation Métallurgique, 1950, Apr.–June, pp. 47–60). A brief survey is made of some recent methods of non-destructive testing (excluding ultrasonic methods). High tension radiographic methods, the use of cobalt 60, electro-magnetic methods (including the Magnetri and Ferrotest, and the Murhometer comparator) are described. Finally, the fluxing method is discussed in which the parts are dipped in an oil bath at 150° C. for 3 min., followed by a petroleum bath, an alcohol bath and a mixture of powdered chalk and alcohol. The oil absorbs the chalk, leaving black streaks indicating the cracks. A fluorescent liquid is often used and the part finally exposed to ultra violet rays in darkness.—R. S.

Ultrasonic Generators. O. Lindström. (Teknisk Tidskrift, 1951, vol. 81, June 2, pp. 473–478). [In Swedish]. The chemical effects of ultrasonic cavitation are briefly outlined and the main types of electric and acoustic ultrasonic generators are described. Cavitation formations achieved by letting steam pass through capillaries as used for making emulsions are also touched upon. There are 34 references.—B. S. E.

Electronic Thickness Gauges. (Teknisk Tidskrift, 1951, vol. 81, May 19, pp. 427–430). [In Swedish]. The principles of electromagnetic, ultrasonic, and radiation-absorption thickness gauges are explained.—B. S. E.

Determination of Stress and of the Lattice Parameters of the Stress-Free Material by Means of One Back-Reflection X-Ray Photograph. R. Glocker. (Zeitschrift für Metallkunde, 1951, vol. 42, Apr., pp. 122–124). A general formula for the determination of the direction of zero extension, as determined by X-ray stress measurements, is developed. Contrary to calculations of A. Durer, the angle of this direction is different in cases of uniaxial and biaxial stress. A method is given which in all cases of uniaxial stress, and in certain cases of biaxial stress, facilitates the determination of the stress from one half of the film, and the measurement of the lattice parameter of the unstressed material from the second half.—P. F.

Non-Destructive Testing Team E.C.A. (Metalen, 1951, vol. 6, July 15, pp. 243–246). [In Dutch]. This report reviews briefly the findings of a small Dutch team which visited the U.S.A. to ascertain how far non-destructive testing methods had been standardized.—R. S.

An Evaluation of Radiography with Particular Emphasis on Detection Methods. C. H. Hastings. (American Society for Testing Materials, Bulletin, 1951, Feb., pp. 66–70). Past and future trends in industrial radiography are discussed. Modifications in technique, which would permit automatic or semi-automatic inspection methods in mass production are desirable if bottlenecks are to be avoided. The application of television techniques is discussed. Another method suggested

is that employing a scanning electronic tube directly sensitive to X- or gamma-radiation.—T. E. D.

The Change in Electrical Resistance of an α-Iron–Carbon Alloy after Quenching. W. Gruhl. (Zeitschrift für Metallkunde, 1950, vol. 41, June, pp. 171–177). Measurements were made of the electrical resistances of wires containing 0·05% carbon, quenched from 700° C. and subjected to various treatments. If they were tempered at once below 200° C. the resistance remained high for a short incubation period; it then decreased to a constant value which was the same for all tempering temperatures. If the wires had been maintained for some time at a lower temperature, before tempering, the incubation period was shorter. It was also greatly lessened by cold working. Wires were also stored for some time at room temperature or above, and then heated to a given temperature for a short time. The resistance decreased to a constant value after a time depending on the temperature and amount of cold working. These results may be explained by Becker's theory. Since the graph of log time against reciprocal of the temperature is a straight line, the rate of attainment of equilibrium depends on the rate of diffusion of carbon through the iron lattice to form a cementite phase. This phase appears as small nuclei, which increase rapidly in number and size as the temperature rises. The nuclei have high surface energies and many are redissolved at higher temperatures, but the amount of cementite phase formed in any temperature range is constant. The nuclei can form during cold storage, although they may not grow; this reduces the incubation period. The effect of cold working is to loosen the forces in the iron crystals, facilitating the migration of the carbon atoms.—N. McE.

Properties of Materials under Superindustrial Stresses. P. W. Bridgman. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author describes experimental work on the effect of stresses, greater than those used at present in industry, on the properties of various materials. Pressures up to 1,500,000 lb./sq. in. were made possible in the work by the use of a new method of packing the joints of pressure apparatus. Chief consideration is given to the great increase in ductility and strain-hardenability of steel under these pressures, and the possibility of wire-drawing under hydrostatic pressure is discussed.—G. F.

Some Results in the Field of High-Pressure Physics. P. W. Bridgman. (Endeavour, 1951, vol. 10, Apr., pp. 63–69). In this account of the apparatus for producing pressures up to 100,000 atm. and the effect of very high pressures on the properties of materials it is mentioned that at 25,000 atm. steel becomes much more ductile and also stronger. Carboloy (a cobalt/tungsten-carbide alloy) becomes stronger in compression and loses its brittleness so that Carboloy pistons can be subjected to pressures of 100,000 atm.—R. A. R.

The Creep of Metals—Definitions, Nomenclature and Methods of Testing. (Metalen, 1951, vol. 6, July 28, pp. 263–268). [In Dutch]. This is a preliminary report of the Dutch Creep Committee of the Bond voor Materialenkennis.—R. S.

Long-Time Elevated Temperature Test of Chromium–Molybdenum Steels. A. B. Wilder and J. O. Light. (Transactions of the American Society for Metals, 1951, vol. 43, pp. 323–341). Typical steels were investigated after 10,000 and 34,000 hr. at 480, 565 and 650° C. Those with less than 1% chromium were severely oxidized, and some of the other steels were subject to graphitization. Steels with 1–12% chromium did not lose Charpy impact strength at room temperature. nor did hardness alter much,—E. T. L.

The Hot-Tearing of Steel. J. M. Middleton and H. T. Protheroe. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 384–400). An apparatus is described for determining the loads a steel will withstand before tearing at high temperatures. The effect of casting temperature, and the influence of composition (for the usual range of concentrations of C, Si, Mn, S, Ni, Cr, Cu, P, Mo, Ti, and V) upon the resistance to tearing, have been investigated. Hot-tearing is more likely to occur and is more severe at high casting temperatures than at low temperatures. Of the elements investigated, sulphur is the most deleterious, even small additions resulting in a lowering of the resistance to tearing. The most beneficial elements are Ti and V. The mechanism of tearing and the effect of variations in hindrance to contraction are discussed. Steels with various sulphur contents were deoxidized with different amounts of aluminium. The results indicate that aluminium has a beneficial effect only if the amounts are sufficient to ensure freedom from grain-boundary inclusions. Larger additions of aluminium result in further improvement, as a result of the alloying effect of this element. Results of an investigation into the tear-resisting properties of killed and semi-killed steels, as normally used for ingot production, are given. The trends with respect to C, S, and Si are the same as when the steels are deoxidized according to accepted foundry practice. In an Appendix M. Thomas and G. F. Komlosy make a statistical analysis of the hot-tear tests.

High Resistance Quality Cast Iron. M. Noris. (Rivista di Meccanica, 1951, vol. 2, Apr. 25, pp. 19–21). [In Italian]. The author reviews the properties which go to make high-quality heat-resisting cast iron. The percentages of carbon, silicon, manganese, phosphorus, and sulphur for iron which will stand up to temperatures of 500° C., 700° C., 800° C., and 1000° C. are discussed. The compositions of corrosion-resisting irons are given and low- and high-silicon irons, and nickel- and chromium-bearing irons are considered.—M. D. J. B.

Graphitization in Heat-Resistant Molybdenum Steels. H-J. Wiester. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, pp. 177–184). The literature on the graphitization of heat-resistant molybdenum steel is reviewed and the conclusions to be drawn therefrom are summarized.—J. P.

Second Report of the Commission on Boron Steels. R. Potaszkin and M. Jaspart. (Société Française de Métallurgie: Revue de Métallurgie Mémoires, 1951, vol. 148, May, pp. 379–412). Part one of this report describes an investigation into the effect of boron (about 0·0008%) on an industrial ingot with small amounts of nickel, chromium, and molybdenum. The improved tensile strength and elastic limit of boron steels are attributed to the pro-eutectoid ferrite precipitating mainly in the acicular form whilst their lower impact strength is due to their more rapid rate of grain growth between 875° and 1100° C. The impact strength may be improved by suitable annealing. Boron has a favourable effect on quenching provided the rate is rapid enough for the austenite to transform below 650° C. In part two, the effect of boron on small casts of carbon steels with other constituents is investigated and found to vary; it is not always beneficial.—A. G.

Properties of Materials and Engineering Uses of Cast Metals. R. W. Bailey. (Institute of British Foundrymen: Foundry Trade Journal, 1951, June 14, pp. 629–636, 641). The importance of tensile and ductility tests on cast metals is assessed, both at low and elevated temperatures. The choice of a material by reason of its fatigue resistance is discussed, and machines for measuring this property are described. The application of spheroidal graphite irons for steam power plant is discussed and finally the use of castings produced by the lost-wax process for the stationary blades in gas-turbine engines is mentioned.—J. E. W.

Recent Progress in Cast Iron and Copper Alloy Foundries. G. Blanc. (Documentation Métallurgique, 1950, Oct.–Dec., pp. 131–148). A broad survey is made of the development of modern foundry products, including pearlitic, acicular or bainitic, and nodular cast irons, and wear-, corrosion-, and heat-resisting cast irons.—R. S.

Cast Iron with Spheroidal Graphite. J. B. Guillaumin. (Métaux et Industries, 1950, No. 1, pp. 11–13). Addition of magnesium to grey cast iron causes the graphite to take spheroidal form, and the mechanical properties of the iron are greatly improved. The resulting iron combines the desirable properties of cast iron and cast steel. The mechanical properties of the magnesium-treated iron are compared with those of untreated iron.—T. E. D.

Acicular Cast Irons. L. A. de Lacerda Santos. (Boletim da Associação Brasileira de Metais, 1951, vol. 7, Jan., pp. 49–65). [In Portuguese]. The author discusses the types of graphite found in cast iron and examines the metallic constituents of cast iron. The use of heat-treatment, inoculation, and of molybdenum and nickel additions to improve mechanical properties is discussed.—R. S.

Heat-Resisting Cast Iron Alloyed with Aluminium. J. Karabula. (Przeglad Odlewnictwa, 1951, vol. 1, Mar., Information Bulletin, pp. 6–7). [In Polish]. The investigation of the structure, hardness, strength, and resistance to oxidation of cast iron alloyed with aluminium (3·4 to 29%) and the method of its preparation are described.—V. G.

Effect of Reheat Treatment on Transverse Ductility in Wrought Steel Products. P. E. Busby, C. V. Klimas, and

C. Wells. (Transactions of the American Society for Metals, 1951, vol. 43, pp. 526–546). Results with a chromium–nickel–molybdenum steel show that a retemper, or a requench and temper, hardly increased the reduction-in-area of the metal.

Mechanical Properties of Metals. H. W. Gillett. (Machine Design, 1951, vol. 23, Mar., pp. 143–148, 198–200). With the sole exception of the modulus of elasticity, none of the values determined by conventional tests can be relied upon as a direct measure of even a single factor of suitability of metals and alloys. The other values increase the metallurgist's understanding of the material but do not lend themselves to the engineer's computations. Their significance in relation to expected conditions of service is appraised.—E. C. S.

Selection of Gear Materials. C. R. Austin. (Machine Design, 1951, vol. 23, Mar., pp. 157–160). The following aspects of gear-tooth surface stresses under specified contact conditions based on investigations of Meehanite metal are discussed: Reason for failure; choice of materials; test made on helical gears; and galling.—E. C. S.

Some Metallurgical Aspects of Ship Steel Quality. H. M. Banta, R. H. Frazier, and C. H. Lorig. (Welding Journal, 1951, vol. 30, Feb., pp. 79s–90s). Semi-killed laboratory heats of 200 lb. can be made with ample reproducibility for studying the influence of chemical composition and deoxidation upon the transition temperature characteristics of ship-plate steels. An increase in carbon, phosphorus, and vanadium contents seemed to raise the transition temperature, whereas an increase in silicon, and to a certain extent sulphur, had no effect. An increase in manganese lowered the transition temperature.—U. E.

Section Thickness in Meehanite Castings. C. R. Austin. (Machine Design, 1951, vol. 23, Feb., pp. 130–131). The physical properties of the engineering-type Meehanite metals are given in a table. Charts show the relation of casting thickness to tensile strength of the section. Specifications are established for the 1-in. section. The tensile strength gradually decreases with increasing section.—E. C. S.

Physical and Mechanical Properties of Segregates in Two Alloy Steels. H. M. Finniston and T. D. Fearnehough. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 5–12). The paper describes techniques for the measurement of hardness variation and tensile and impact properties of segregates isolated from two alloy-steel forgings. The quantitative differences in properties between the segregates and the matrices surrounding them after various heat-treatments are detailed and the former are shown to be significantly harder, and to have a higher proof and maximum stress and lower elongation and impact values on all casts. The differences in chemical composition between segregate and matrix are also reported quantitatively. Photomicrographs are shown of the structures of segregate and matrix, and attention is drawn particularly to the variations in structure and concentration of non-metallic inclusions within the segregate. The influence of the inclusions on the mechanical properties of the segregate is discussed. Photomacrographs which indicate the mode of formation of segregates are given.

The Mechanical Properties of Nickel Alloy Steels. (Mond Nickel Co., Ltd., Publication, 1951). This 84-page publication summarizes in tables and graphs the mechanical properties of representative heat-treatable nickel alloy steels to provide a convenient reference for the use of engineers, designers, metallurgists, and heat-treatment superintendents.—R. A. R.

METALLOGRAPHY

Metal Fractures Modelled by Other Materials. A. M. Sullivan and J. A. Kies. (Journal of Metals, 1950, vol. 188, Sept., pp. 1090–1091). The authors describe and illustrate how the surfaces of plastics fractured by various methods may be used as convenient models in the study of the morphology of metal fracture.—G. F.

Fundamentals of Metallography of Cast Iron. M. Dubowicki. (Mechanika, 1949: Przeglad Odlewnictwa, 1951, vol. 1, Apr., pp. 107–113, May, pp. 137–142). [In Polish]. The influence of the usual impurities (Si, Mn, P, S, and Cu) of alloying elements (Cr, Ni, Al, Co, Mo, Ti, V, and W) and of hydrogen, oxygen, and nitrogen on the microstructure and properties of cast iron is described.—V. G.

An Exposure Meter for the Electron Microscope. E. H. Frei and F. L. Hirshfeld. (Review of Scientific Instruments, 1951, vol. 22, Apr., pp. 231–232). The exposure meter reported here measures directly the beam current reaching the fluorescent viewing screen of the electron microscope. The principle of the method is to allow the beam to charge a condenser. The time for the potential across the condenser to reach a certain value is measured.—J. A. L.

Homogenization and Dehomogenization in Steels. M. L. Colombier. (Documentation Métallurgique, 1950, July–Sept., pp. 87–106). The author discusses the type of treatment necessary to endow the heterogeneous solid solutions with a tendency to homogeneity. Dehomogenization phenomena which interrupt this process after solidification are described. Proof is given that the homogenizing treatment does act on the inclusions which are not dissolved in the solid solution as well as on the dissolved inclusions.—R. S.

Le Chatelier's Principle and Its Applications in Metallurgy. M. B. Bever and R. Rocca. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, May, pp. 363–368). The principle and its interpretation are discussed. Metallurgical applications are mainly to the effect of heat and pressure on reactions and phase changes but light is also thrown on the solution of hydrogen in metals, the solution of chromium in γ-iron, and elastic deformation.—A. G.

Kinetics of the Austenite Transformation in Certain Alloy Steels. E. A. Loria. (Transactions of the American Society for Metals, 1951, vol. 43, pp. 718–733). The **S**-curves of six chromium–molybdenum steels are presented. These show a region of stability of austenite between the pearlitic and bainitic regions. The author discusses the equivalence of the effects of different elements in the steel.—E. T. L.

Isothermal Transformation Diagrams for Nickel Steels. I—General Discussion of Diagrams. II—Practical Applications and Diagrams for Individual Steels. (Mond Nickel Company: Metallurgia, 1951, vol. 43, May, pp. 234–242; June, pp. 280–288). Reference is made to microscopic, dilatation, and X-ray methods of determining isothermal transformation diagrams, in particular the procedure adopted by the Mond Nickel Company. There follows a brief outline of the ideas of nucleation and grain growth, especially pearlite formation, with some photographs showing the progress of the change of microstructure during transformation. The effects of alloying elements are mentioned, also the martensite reaction, the formation of retained austenite, the influence of structure on mechanical properties, and the limitations of the diagrams. In Part II a group of curves gives the temperature–time distributions in cooling steel bars, and these are considered along with **S**-curves for 13 En steels, in deducing appropriate heating and cooling cycling for martempering, austempering, and annealing.—E. T. L.

Structural Transformations in the Tempering of High-Carbon Martensitic Steels. K. H. Jack. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 26–36). New X-ray observations give direct evidence that the loss of tetragonality of martensite during the first stage of steel tempering is caused by the precipitation of a close-packed hexagonal iron carbide of composition near Fe_3C. It is proposed that this iron carbide should be named ϵ-iron carbide, because of its structural similarity to ϵ-iron nitride. The ϵ-iron carbide is formed as a coherent transitional phase in which relaxation of the Laue condition for X-ray reflection is a minimum in a direction normal to the (101) lattice planes. The existence of a simple orientation relationship between martensite and the hexagonal carbide is probable. During the third stage of steel tempering, ϵ-iron carbide transforms to give a fine dispersion of very thin platelets of cementite, with the planes of the platelets parallel to the (001) lattice planes of the cementite structure. The observed X-ray diffraction pattern is markedly different from that of high-temperature crystalline cementite, as the Laue condition is completely fulfilled only in directions parallel to the (001) planes, and is relaxed in the [001] direction. Included among the strongest reflections are those corresponding to previously unidentified X-ray reflections observed by earlier investigators and ascribed by them to a new unknown iron carbide. With increasing tempering times, or at higher temperatures, the gradual growth and recrystallization of the cementite platelets are accompanied by reduction in the lattice strain of the matrix. Each of the two stages of the transition of martensite to cementite (corresponding to the first and third stages, respectively, of steel tempering) can take place by relatively small movements of iron atoms, and the precise nature of

these movements is suggested. The proposed structural changes are correlated with the well-known changes in hardness and specific volume of steel during tempering, and are supported by recent electron-microscope studies. Cementite platelets similar to those observed in tempered martensites are also obtained in the low-temperature heat-treatment of carbonyl-iron powders.

The Kinetics of Isothermal Growth of Martensite Crystals. B. Ya. Lyubov. (Doklady Adademii Nauk U.S.S.R., 1951, vol. 78, No. 5, pp. 895–898). [In Russian]. The relationships describing the kinetics of isothermal growth of martensite crystals are derived from theoretical considerations.—V. G.

Magnetic Evidence of Negative Cobalt and Iron Ions in Alloy Melts and in Very Dilute Solid Solution Alloys. E. Vogt. (Zeitschrift für Metallkunde, 1951, vol. 42, May, pp. 155–158). The transition elements chromium to cobalt dissolve in copper, silver, and gold showing paramagnetism obeying the Curie law, from which the atomic moment of the open *d*-shell of the solute atom is calculable. Palladium however 'dissolves diamagnetically,' and nickel with a weak temperature-independent paramagnetism, indicating a filled *d*-shell. A calculation by K. Schubert also indicates that only 10% of the dissolved nickel atoms have an unfilled *d*-shell at room temperature. Measurements by M. L. Weil show that in melts of alloys having a polyvalent base (Sb), dissolved cobalt loses its normal paramagnetic temperature dependence, while in the case of dissolved iron the temperature dependence is strongly reduced. This indicates greater filling of the *d*-shell, and if paramagnetism is taken to be associated with a complated *d*-shell, the experimental results would point to the existence of negative cobalt and iron ions in the melt. If K. Schubert's explanation is accepted that the anomalous temperature dependence of the susceptibility results from an increase of *d*-shell vacancies with increasing temperature, then the *d*-shell is not filled sufficiently to facilitate negative metal ion formation. Measurements by F. Bitter indicate that in dilute (0·7–0·008% Fe) solutions of iron in copper the atomic moment of the iron falls at low temperatures to a value close to that corresponding to the Fe-ion.—P. F.

Thermodynamics of the Iron–Carbon System. F. Munoz del Corral. (Instituto del Hierro y del Acero, 1951, vol. 4, Jan.–Mar., pp. 52–61; Apr.–June, pp. 131–136). [In Spanish]. A coherent thermodynamic interpretation of the iron–carbon system is established on the basis of experimental determinations of the activity of carbon in the different forms of iron. Values are obtained for the free energy of the formation of cementite from the various allotropic forms of iron. The stability of the carbide, the formation and stability of the cementite, and the influence of silicon and manganese are discussed.—R, S.

Main Characteristics of Phase Equilibrium of High-Coercive Iron–Nickel–Aluminium Alloys. O. S. Ivanov, (Doklady Adademii Nauk, U.S.S.R., 1951, vol. 78, No. 6, pp. 1157–1160). [In Russian]. Phase diagrams based on: (1) Dilatometric curves; (2) electrical-resistance/temperature curves; and (3) the physical properties and microstructure of an Fe–Ni–Al alloy are given, and the main characteristics of the phase equilibrium are discussed.—V. G.

CORROSION

Reactions in the Solid State in Oxide Films or Layers on Iron. E. A. Gulbransen. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, May, pp. 336–352). Thermodynamic calculations on the reactions involved are given with details of an investigation using an electron reflection technique. The kinetics of the reaction between the oxide film and the underlying iron to form ferrous oxide and of the reversible reaction $Fe_3O_4 + Fe \rightleftharpoons 4FeO$ have been studied and possible mechanisms suggested. A. G.

The Results of One Year's Accelerated Corrosion Testing on Various Steel Finishes. L. A. Williamson. (Ministry of Supply, Telecommunications Research Establishment, Gt. Malvern, 1951). Thirty steel specimen plates protected by paint, metal spray, and electroplating, either singly or in combination, have been subjected in a climatic chamber to cycles of 12 hr. at 60° C. with saturation, alternating with 12 hr. at 25° C. which caused copious deposits of condensate to settle. After one year two-thirds of the specimens had been eliminated. Full details of the coatings, testing equipment, and results are given.—R. A. R.

The Mechanism of the Protection of Iron from Corrosion by Sodium Nitrite. I. L. Rozenfel'd. (Doklady Akademii Nauk, U.S.S.R., 1951, vol. 78, No. 3, pp. 523–526). [In Russian]. On the basis of experimental evidence it is concluded that the action of sodium nitrite as an inhibitor of corrosion is due to a retardation of anodic processes and therefore it should be classified as an anode inhibitor. For this class of inhibitor, effective protection can be obtained only when the anode process is completely stopped. With insufficient inhibitor a considerable part of the surface is screened but the velocity of corrosion on unprotected parts is increased.—V. G.

The Mechanism of Corrosion Fatigue. G. V. Karpenko. (Doklady Adademii Nauk, U.S.S.R., 1951, vol. 77, No. 5, pp. 827–830). [In Russian]. The mechanism of corrosion under the influence of alternating load in a corrosive medium is discussed. The author believes that corrosion fatigue consists of two consecutive processes: (1) The development of microcracks whose formation is accelerated by the adsorption of ions; and (2) the true corrosion process (electrochemical corrosion) inside these cracks which makes them grow. The first process causes the formation of a great number of microcracks which are orientated perpendicularly to the active stresses. This mechanism explains the selectivity of 'deep corrosion,' preferential formation of transcrystalline cracks, and the impossibility of complete protection. Protection stops the electrochemical process of corrosion inside cracks.—V. G.

The Dependence of the Velocity of Solution of Steel in Sulphuric Acid on Pressure. S. A. Valezin and A. G. Tulaeva. (Doklady Akademii Nauk, U.S.S.R., 1951, vol. 78, No. 1, pp. 75–77). [In Russian]. The velocity of solution of steel in aqueous solutions of mineral acids depends considerably on the gas pressure over the acid. The authors investigated the influence of pressure on steel solubility in pure 5 *N* H_2SO_4 and in the presence of inhibitors (formaldehyde and thiodiglycol) and a stimulant (paranitraniline). In pure acid the velocity of solution at 15 mm. pressure was half that at normal pressure. This is explained by the formation of hydrogen bubbles on the steel surface which at low pressures are formed more readily. In the presence of thioglycol the velocity of solution is practically constant since the evolution of hydrogen is very small. The stimulating effect of paranitroaniline is diminished by the increase in pressure.—V. G.

The Role of Current Distribution in Cathodic Protection. H. D. Holler. (Journal of Research of the National Bureau of Standards, 1951, vol. 47, July, pp. 1–14). The paper outlines a procedure for determining current distribution over an electrode surface, as required in cathodic protection or in electroplating when the electrode potential bears a known relation to current density. It shows the relation of current distribution to resistance of current path and counter electromotive force. The primary current distribution (without polarization) is also computed. A method is suggested for determining the electrode potential/current-density relation over an extensive surface in a uniform medium. In a non-uniform medium, the determination of current density by measurement of electrode potential becomes complex. In such a case the potential criterion of cathodic protection must be relied upon.

Corrosion of Steel Railway Sleepers: Final Report. J. C. Hudson. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 13–16). The wastage, caused by rusting and abrasion, of copper-bearing steel sleepers has been compared with that suffered by ordinary mild-steel sleepers in service tests lasting up to 14 years and made at five places on the British Railways (Western Region). Except in a railway tunnel, the copper-bearing steel was between 20 and 70% better than mild steel. Ordinary mild-steel sleepers, weighing 150 lb., should last for about 10–100 years, according to the locality, before they lose one-quarter of their original weight. Under normal circumstances, therefore, the resistance of steel sleepers to rusting is adequate, but it can be appreciably increased, if desired, for sleepers laid in the open by using copper-bearing steel.

Research on the Characteristics and Properties of Wrought Iron. N. Collari and N. Fongi. (Calore, 1951, vol. 22, July, pp. 255–262). [In Italian]. A study is made of the comparative oxidation of wrought iron and ordinary steel when hot. Wrought iron is more resistant due to the higher content of phosphorus which makes a protective surface containing an oxidized form of iron phosphide.—M. D. J. B.

Protection against Corrosion. I—Text and Figures. II—Graphs. (General Report on the Work of Commission No. IV, Association Belge pour l'Etude, l'Essai et l'Emploi des Matériaux, 1951, Mar. 28). The organization and results of a large-scale research programme on the prevention of corrosion, carried out in 1948 to 1950, are reported. The work included a detailed study of undercoats, accelerated ageing, and the physical and mechanical properties of paints. In addition, metal coatings, preparation of metallic surfaces before painting, and the use of low-alloy steels were investigated. The paint compositions are tabulated.—T. E. D.

ANALYSIS

Sampling of Ferrous and Non-Ferrous Alloys—A Bibliography. A. C. Holler, (American Society for Testing Materials, Bulletin, 1951, May, pp. 66–67). This bibliography, which was prepared under the auspices of A.S.T.M. Committee E-3, Division S, Subcommittee S-2, is intended to serve as a guide to future sampling techniques. There are 52 references including 13 on ferrous metals.—T. E. D.

Spectrographic Analysis of Chromium Plating Baths. M. Jean. (Revue Générale de Mécanique, 1951, vol. 35, July, p. 211). The analysis includes the determination of chromic acid, trivalent chromium, sulphuric acid, and iron. A summary is given of the author's work as presented at the 1951 Conference of the Centre d'Information du Chrome Dur.—R. S.

Theory and Practice in Quantometry. (Spectrographer's News Letter, 1950, vol. 3, Aug.). This article deals with the theoretical basis for the direct-reading system. An alternative to the usual double-reading system, used when the internal standard element varies in concentration, is given.

Photoelectric Instruments for Chemical Analysis. M. Hultin. (Teknisk Tidskrift, 1951, vol. 81, June 9, pp. 501–502). [In Swedish]. The author stresses the importance of using instruments of high quality with a carefully worked out standard technique. Calibration of spectrophotometers and photoelectric colorimeters should always be carried out by the user since American enquiries have shown values to be insufficiently accurate in more than 60% of the investigated cases.—B. S. E.

A New Deflection Type Densitometer. W. G. Kirchgessner. (Review of Scientific Instruments, 1951, vol. 22, May, pp. 289–292). The author discusses the design and performance of the Bausch and Lomb 33–84–91 densitometer for measuring the relative intensity of a photographic record of spectral systems. Fundamental requirements of design are stated and construction is described on the basis of these requirements. Performance data are discussed in detail and records are given to demonstrate its fidelity of reproduction.—J. A. L.

Colorimetric Determination of Iron—A Review of Known Methods. T. S. West. (Metallurgia, 1951, vol. 43, Apr., pp. 204–206 ; May, pp. 260–264 ; June, pp. 311–316). This well-documented review deals with methods of estimation using ortho-phenanthroline or α, α′-dipyridyl. Details are given of the scope and variations of each method.—E. T. L.

Determination of Hydrogen in Liquid Steel. R. M. Cook and J. D. Hobson. (Journal of The Iron and Steel Institute, 1951, vol. 169, Sept., pp. 24–25). A comparison between two methods for the determination of hydrogen in liquid steel is given as a result of collaborative work between two laboratories. The methods employ a sealed mould and a quenched notched pencil, which have been developed in the respective laboratories. Results are given for 15 casts made by acid and basic open-hearth, and basic electric-arc processes, and sampled at the works with which the authors are associated. Satisfactory agreement is shown for comparative results obtained by the two methods.

The Colorimetric Determination of Silicon in Steel and Cast Iron. L. Kučera. (Iron and Steel Institute, 1951, Translation Series No. 424). This is an English translation of a paper which appeared in Hutnické Listy, 1950, vol. 5, June, pp. 102–106 (*see* Journ. I. and S.I., 1951, vol. 168, May, p. 114).

Qualitative Analysis of Alloy Steels. C. Beermann and H. Hartmann. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, May–June, p. 159). A sample of steel borings is fused in sodium peroxide, leached with water, and the solution rendered neutral by boiling with ammonium chloride. A spot test with 8-hydroxyquinoline allows vanadium (less than 0·2% in the steel) to be readily detected. Mn, Cr, Mo, and W may also be detected by spot tests.—J. P.

Methods of Analyzing Coal and Coke. A. C. Fieldner and W. A. Selvig. (United States Bureau of Mines, 1951, Bulletin 492). The bulletin has been published to provide information concerning the standard methods of analysing coal and coke employed in the U.S. Bureau of Mines laboratories.—B. G. B.

The Spectrographic Determination of Alumina in Silica Brick. G. L. Mason and G. E. Speight. (Transactions of the British Ceramic Society, 1951, vol. 50, Jan., pp. 35–46). A spectrographic technique for the rapid determination of alumina in silica brick (0·20–1·50% Al_2O_3) has been developed and detailed results are presented on a series of 23 routine samples. The sample, mixed with graphite, is excited by an intermittent A.C. arc discharge. The mean result of three exposures shows good agreement with chemical results (± 0·05% alumina) and closer agreement is obtained from the average of two such sets of exposures. The method has marked advantages for routine control purposes.

HISTORICAL

1851–1951 : The Pattern of Progress in Iron and Steel. M. Davies. (British Steelmaker, 1951, vol. 17, June, pp. 277–284). The author outlines the development during the last 100 years of the iron and steel industry.—G. F.

Fifty Years of Steel. W. S. Tower. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The evolution of the American iron and steel industry during the last 50 years is discussed.—G. F.

The Charcoal Iron Industry in the Early Eighteenth Century. B. L. C. Johnson. (Geographical Journal, 1951, vol. 117, June, pp. 167–177, Preprint). The locations and capacities of iron furnaces and forges in 1717 are given. For the country as a whole, pig-iron production and consumption were approximately balanced, but significant discrepancies existed in several regions between the pig-producing and consuming capacities of the furnaces and forges respectively.—T. E. D.

The Early Iron Industry in North Wales. A. S. Davies. (Transactions of the Newcomen Society, 1945–46 and 1946–47, vol. 25, pp. 83–90). Blast-furnaces in North Wales have been known from 1650 onwards. Difficulties in charcoal supplies curbed production in the 18th century. Details of forges and blast-furnaces up to 1855 are given.—T. E. D.

Ferrous Metallurgy : 100 Years' Contributions by the Royal School of Mines. G. B. Willey. (Iron and Steel, 1951, vol. 24, May, pp. 151–156). This is a brief review of the many contributions to the advancement of ferrous metallurgy made by the Royal School of Mines in the 100 years since its opening. Special mention is made of the work of Sir William Roberts-Austen and Sir Harold Carpenter.—G. F.

Chemical and Metallurgical Equilibrium in the Work of Henry Le Chatelier and in Present Science. M. Rey. (Revue de Métallurgie, Mémoires, 1951, vol. 48, Mar., pp. 161–172). The work of Le Chatelier is discussed in relation to the present state of knowledge of : (*a*) Chemical equilibrium at high temperatures, including free energy, chemical affinity, and thermodynamic equations and data ; and (*b*) the equilibrium of solutions including alloys and slag–metal mixtures.—A. G.

1851–1951. A Hundred Years of Metallurgy. L. Aitchison. (Sheet Metal Industries, 1951, vol. 28, May, pp. 405–424 ; June, pp. 519–526, 530). An historical account is given of the development of both the ferrous and non-ferrous metallurgical industries. A very wide field is covered and attention is given to the following : Faraday's electrical discoveries leading to the large-scale production of aluminium and magnesium, Bessemer's invention of the method for producing mild steel in a single-stage process ; the development of the open-hearth steelmaking process, and the Thomas and Gilchrist method for ulitizing phosphoric ores ; the birth of the alloy age and the development of high-speed, high-tensile, and stainless steels ; the discovery of precipitation hardening, and the development of such non-ferrous alloys as Duralumin ; the application of the microscope to the examination of structures, and the general development of ordered scientific research.—P. M. C.

The History of Electrodeposition. R. C. Davies. (Sheet Metal Industries, 1951, vol, 28, May, pp. 477–481). Electroplating and electrorefining are among the industrial processes pioneered by Great Britain, and they led directly to the invention of the first electrical generator. A brief account is given of these developments from the first electrodeposition of copper by Nicholson and Carlisle in 1800.—P. M. C.

The Truth about Dud Dudley. H. R. Schubert. (Journal of The Iron and Steel Institute, 1950, vol. 166, Nov., pp. 184, 185).

Ironmasters of Coalbrookdale. R. R. Adler. (Steelways, 1951, vol. 7, July, pp. 21–24). This is an historical account of the development of the coke smelting process for the production of iron. Abraham Darby in 1708 or 1709 was the first man successfully to substitute coke for wood charcoal, and the process was further developed by his son and grandson.—P. M. C.

Notes on the History of Hayle Foundry. T. R. Harris. (Engineering, 1951, vol. 172, July 27, pp. 102–103). This article describes the origins and development of the Hayle Foundry of Harvey and Co. which was founded in the late 1770's by John Harvey. Much information is given of historical engineering interest.—M. D. J. B.

The 2000-Year Tradition of the Austrian Iron and Steel Industry. R. Walzel. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 364–373). The growth of the Austrian iron industry, which is based on two main sources of ore in Carinthia and Styria, is traced from early Roman times to the present day, particularly in regard to the development of the modern coke blast-furnace from early reduction furnaces.

ECONOMICS AND STATISTICS

Taxation and Export Trade of the Iron and Steel Industry. W. Schubert. (Stahl und Eisen, 1951, vol. 71, Apr. 26, pp. 467–470). The influence of taxes on export prices and a comparison of taxation in various countries are employed to indicate how Germany's ability to obtain and maintain an iron and steel export trade is adversely affected.—J. P.

The Schuman Plan—A Summary and Interpretation of the Paris Treaties. K. Blankenagel. (Stahl und Eisen, 1951, vol. 71, May 10, pp. 498–499).

Swedish Iron Making As It Is at Present. N. Elfström. (Teknisk Tidskrift, 1950, vol. 80, Dec. 9, pp. 1125–1130). [In Swedish]. It is hoped that new dephosphorization methods will make the great iron-ore reserves of 2200 million tons workable. Sponge iron replaces scrap more and more and greater use of electric power reduces the fuel requirements. The labour shortage is still serious, and it is estimated that about 6% of the labour employed in the Swedish iron industry are workmen from abroad.—B. S. E.

Conservation of Manganese. S. Marshall. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 186–188). There are no practical methods for greatly reducing the consumption of manganese without losses in production in both steel mills and plants. Stock-piling of high-grade manganese ore and the investigation of methods of beneficiation of U.S.A. low-grade ores and waste slags are recommended in order that industry may weather a manganese crisis.—F. C.

The Freedom Bringing Soviet Union. (Kohászati Lapok, 1951, vol. 6, Mar., pp. 49–50). [In Hungarian]. Information is given on Russian technical assistance to the Hungarian iron and steel industry. This took the form of improvement in casting technique for steel for rails and boiler plates; improved utilization of phosphoric iron ores; and preventing flakes and other defects in forgings. The Danube Ironworks are being built on the basis of Russian experience. Several Russian specialists are permanently in Hungary to act in an advisory capacity.—E. G.

Australian Steel Plans. (British Steelmaker, 1951, vol. 17, Apr., pp. 191–195). This article describes the plans of the Broken Hill Proprietary Co., Ltd., to raise Australia's annual steelmaking capacity from its present level of nearly 2,000,000 tons to 2,300,000 tons by 1952.—G. F.

Sweden's Iron and Steel Industry. T. L. Joseph. (Journal of Metals, 1951, vol. 3, July, pp. 507–510). The author gives a brief outline of the Swedish iron and steel industry, dealing with the mining, concentrating, and sintering of iron ore, and the production of iron and steel.—G. F.

Capital Requirements and Productivity. C. M. White. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The author discusses the need for increased productivity in the American iron and steel industry, and the provision of the capital required to finance its expansion.—G. F.

Iron Ore in an Expanding Steel Industry. E. Hoyt, jun. (American Iron and Steel Institute, May 23–24, 1951, Preprint). The problem of increasing the iron-ore supply to meet the requirements of the expanding American iron and steel industry is discussed.—G. F.

Metallurgical Production in Catalonia. S. Vilardell. (Metalurgia y Electricidad, 1951, vol. 15, June, pp. 54–55). [In Spanish]. Metal working is second to the textile industry in Barcelona and owes its importance to the latter, though the metallurgical tradition is of long standing. Catalonia relies on scrap and ingots from Vizcaya, Asturias, Ponferrada, and Sagunto.—R. S.

Catalonia has a Very Efficient Iron and Steel Industry. F. Baratech. (Metalurgia y Electricidad, 1951, vol. 15, June, pp. 50–52). [In Spanish]. The Catalonian iron and steel works are listed. Steel output in the province of Barcelona is 30,000 tons a year (5% of total Spanish output). Present capacity is 60,000 tons, provided sufficient raw materials and electricity are available. Lack of large blast-furnaces has led to the tendency to produce quality steels for the textile and other engineering industries. Present and future possibilities of expansion are indicated.—R. S.

Some Remarks on the Extent and Importance of the Metal Industry in Brazil. A. Groothoff. (Metalen, 1951, vol. 6, June 15, pp. 207–212; June 30, pp. 228–231; July 15, pp. 247–253). [In Dutch]. Following a general description of Brazil, the development of the main centres of the Brazilian iron and steel industry is sketched from the economic point of view.—R. S.

The Spanish Iron and Steel Problem. R. Guevara Lizaur. (Instituto del Hierro y del Acero, 1951, vol. 4, Apr.–June, pp. 98–111). [In Spanish]. The relationships between the types of raw material available and the selection of steel-making methods are discussed. Fixed open-hearth furnaces are well suited to deal with Spanish ores. Duplexing is considered in the light of Spanish conditions. The characteristics of the steels made by the processes are outlined—R. S.

Possibilities of Iron and Steel Making in India without Coking Coal. H. Schrader and D. J. Ram. (Journal of Scientific and Industrial Research, 1951, vol. 10A, Apr., pp. 157–165; May, pp. 185–198). Of India's 16,500 million tons of workable coal 2,000 million tons are suitable for coking and this is sufficient to smelt only a quarter of the 10,000 million tons of high-grade ores. The prospects of using the acid Renn process are considered.—E. J. B.

The Present Metallurgical Bases of Austrian Iron and Steel Production. B. Matuschka. (Journal of The Iron and Steel Institute, 1951, vol. 168, Aug., pp. 343–345). A description is given of the present distribution and sources of iron and steel production in Austria. It is shown that good conditions exist for the production of a large proportion of high-quality steel. Plans for the future production of steel in Austria are discussed, and a brief comparison is made between the expected distribution in Austria, once new plant now being constructed at Donawitz and Linz is in operation, and production in Europe as a whole.

Economics of the Combined Operation of Metallurgical Plants and Mines. F. Wesemann. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 697–701). The economics of joint operation are discussed with particular reference to the siting of coke ovens for metallurgical coke in the Ruhr district and other German and European industrial regions.—J. P.

MISCELLANEOUS

Titanium and Its Alloys. (Journal du Four Electrique, 1951, vol. 60, Jan.–Feb., pp. 17–18; Mar.–Apr., pp. 43–44). Pure titanium is difficult to obtain because the ores are not pure and because of the ease with which the pure metal forms oxides and nitrides at above 600° C. This necessitates working in an inert-gas atmosphere. The usual industrial preparation of titanium is via the preparation of $TiCl_4$ which is passed over magnesium metal heated to 850–900° C. to yield metallic titanium. Other methods of preparation are described. The metallic titanium produced is in powder state. There are three processes of compacting it: (1) Application of high pressure at elevated temperature (1100–1200° C.) in an inert atmosphere; (2) heating in a closed tube to 900° C., fused in an argon atmosphere by an electric arc; and (3) fusion in a graphite or thoria crucible by induction heating. Each process has its special advantages. Titanium and its alloys possess high rupture stress together with good corrosion resistance for given density. They should find application in marine and aeroplane construction and also in

industrial chemical plant. Prices for titanium in sponge, bar, and sheet form in francs/kg. are 3850, 7800, and 15,600, respectively.—B. G. B.

Dust, Fume and Smoke Suppression. A. J. Grindle. (Iron and Steel Engineer, 1951, vol. 28, July, pp. 87–94). The author discusses the problems of air pollution and the rules and regulations applicable in the large cities of the U.S.A. to enforce air-pollution control. Methods of recording air contaminants and density of smoke are described, and consideration is given to the efficiency of several types of dust-catching equipment.—M. D. J. B.

Problems of Air Pollution. A. D. Brandt. (Association of Iron and Steel Engineers, Yearly Proceedings, 1950, pp. 322–330). The author considers in detail the various contaminants including smoke, soot, fly ash, cinders, dirt, carbon, oxides of metals, silicates, silica, sulphur dioxide, and carbon monoxide and dioxide. The concentration of pollutants is discussed and statistical data on pollution in the principal cities of the U.S.A. are given. The influence of metrology and topography on pollution are examined as well as the effects of pollution.—M. D. J. B.

Development and Application of the Statistical Method of Research. K. Daeves. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 715–726). The statistical method of investigation is discussed and examples quoted. The applicability and advantages of frequency analysis and the use of special graphical techniques are described.—J. P.

Application of Statistical Methods to the Quality Control and Development of Materials. E. Rossow. (Stahl und Eisen, 1951, vol. 71, June 21, pp. 649–664). The general applicability of statistical methods to production control and design of experiments is discussed. Recommendations are made for the preparation of characteristic diagrams for assessing statistical testing programmes and for the use of special paper for indicating types of distribution and for control diagrams.—J. P.

Where Do We Stand with our Systems of Units? W. Janizki. (Microtecnic, 1958, vol. 2, Oct., pp. 212–214; Dec., pp. 277–280; 1949, vol. 3, Jan.–Feb., pp. 45–47; Mar.–Apr., pp. 94–95; May–June, pp. 140–144; July–Aug., pp. 194–198; Sept.–Oct., pp. 244–246; Nov.–Dec., pp. 295–299; 1950, vol. 4, Mar.–Apr., pp. 110–113; May–June, pp. 148–151; July–Aug., pp. 231–234; Sept.–Oct., pp. 290–293; Nov.–Dec., pp. 347–350; 1951, vol. 5, Mar.–Apr., pp. 101–104; May–June, pp. 124–126). The author deals with the changes which have recently taken place in the field of measurements owing to the replacement, on January 1, 1948, of the electrotechnical 'international' units by the 'absolute' units. He surveys measuring systems in use since 1797. He reviews the characteristics of the Giorgi measuring system and discusses the prospects of improving the existing systems by introducing the 'dimensional coherence.' The dimensional coherence of the Giorgi-Kalataroff system is also considered.—R. A. R.

Radioactive Isotopes and Radiographs in Metallurgy. A. Vašíček. (Hutnické Listy, 1951, vol. 6, Apr., pp. 179–181). [In Czech]. The author reviews briefly the development of radioactive isotopes and enumerates their practical applications in metallurgy, *e.g.*, determination of the phosphorus and sulphur contents of melts, investigation of the solubility of one metal in another, investigation of the diffusion of metals, and friction between two metal surfaces.—E. G.

Radioactive Elements in the Study of Steels and Industrial Processes. A. Kohn. (Société Française de Métallurgie: Metal Treatment and Drop Forging, 1951, vol. 18, June, pp. 239–245; July, pp. 289–296). *See* Journ. I. and S.I., 1951, vol. 169, Nov., p. 317.

Research and Development at Simon-Carves. W. R. Thomas. (Coke and Gas, 1951, vol. 13, July, pp. 235–243). New research and development laboratories built by Simon-Carves, Ltd., at Stockport are described. The problems to be studied and the facilities provided are enumerated.—T. E. D.

Recent Developments at Home and Abroad in the Construction of Large-Scale Oxygen Generating Plants. E. Karwat. (Stahl und Eisen, 1951, vol. 71, July 5, pp. 709–715). The construction of large-scale oxygen plants in America employs, in general, the same methods as used in Germany. The differences in type and sequence of steps in heat exchange, refrigeration, and rectification are discussed and the designs of the various makers are compared.—J. P.

Principles of Oxygen Production. E. G. Hickling. (American Institute of Mining and Metallurgical Engineers, Open Hearth Conference Proceedings, 1950, vol. 33, pp. 34–42). A description of the principles underlying the commercial production of liquid and gaseous oxygen is given.—F. C.

Determination of the Most Economic Diameter of Tubes Roughened Internally in Service. W. Toussaint. (Stahl und Eisen, 1951, vol. 71, June 7, pp. 612–629). A newly developed graphical procedure facilitates the calculation of suitable tube diameter, correct flow rate, pressure drop and estimated yearly costs for pumping, under conditions of changing internal roughness use with any gas or liquid.—J. P.

BOOK NOTICES

"*Compressed Air in Mining and Industry.*" Compiled and edited by S. H. North. 8vo, pp. ix + 170. Illustrated. London, 1951: Sir Isaac Pitman and Sons, Ltd. (Price 18*s.*)

The tempo of engineering and scientific progress makes it quite impossible for the technical man to keep abreast with latest developments. There are many, however, who wish to acquire some knowledge on specialized equipment and who, as users and potential purchasers, must be able to assess the relative merits of comparable machinery available on the market. In the past few years much has been published on a wide variety of subjects with this aim in view.

This book "Compressed Air in Mining and Industry" gives much information on all types of compressed-air equipment ranging from large turbo-compressors down to pneumatic hand tools. The book aims at giving more than a review of current machinery and provides some useful fundamental data on the principles of compressors, on compressed air as a form of power, and on machinery which can be operated by this means. Design and operating characteristics of equipment are given accompanied by the type of considerations which would lead one to chose between one machine and another.

Rather than describe a great number of individual machines, the author describes the nature of the work which is done in mining, industry, and public works, and how compressed air can be brought to the service of the engineer, production man, commercial user, and tradesman. This makes reading very much more interesting and prevents the contents of the book from becoming catalogue material, as is often the case in this type of work.

The book, which comprises 11 chapters, is divided broadly into two parts. The first deals with the uses of compressed air in mines, quarries, industry, construction, and public works; the second with the machinery itself including conveyors, portable compressors, and pneumatic tools and appliances. The care and treatment of this machinery and oil, dust, heat, lubrication and the elimination of moisture, are also adequately dealt with.

The book draws much from the author's wide experience on this subject and from the expert knowledge of a number of specialists and firms frequently referred to and quoted throughout the text. It should appeal to all interested in compressed air as a source of power. The text is simple to understand and contains a wealth of information. The quality of the photographic reproductions might perhaps have been better.—M. D. J. Brisby

Simons, E. N. "*Cutting-Tool Materials.*" 8vo, pp. ix + 180. London, 1951: Sir Isaac Pitman and Sons, Ltd. (Price 21*s.*)

With this volume the author adds another to his already lengthy list. The contents embrace plain carbon and alloy steels, high-speed steel, Stellite, and cemented carbides. Two chapters are devoted to welded tools and the author has considered die steels as coming within his field. The composition, treatment, and application of these materials are covered in straightforward language, no specialized metallographic knowledge being required by the reader. In addition there are chapters on the grinding, and the testing and inspection of tool materials.

A notable part of the book is the appendices, particularly those which give the recommended tool materials for about 800 different purposes. This extensive list is arranged in

alphabetical order and there are also appropriate references to the text for details of heat-treatment.

It will be seen that the work will be an extremely useful and comprehensive handbook "to all engaged in the design, production, and use of cutting tools." It is well written in the clear manner we have come to expect from this author. The volume is very nicely produced.

A. R. BAILEY

SPOTTS, M. F. "*Design of Machine Elements.*" 8vo, pp. x + 402. Illustrated. London, 1951: George Allen and Unwin, Ltd. (Price 25*s.*)

There are limits to the engineering knowledge which can be acquired by practical experience and common sense but there comes a point where knowledge can advance no further without the help of theoretical concepts. The formulation of these belongs to the engineering science of applied mathematics, and their solution to the realm of pure mathematics.

As mechanical sciences progress the engineer is inevitably faced with problems of growing complexity; machines have developed to such an extent that to effect even a small improvement now requires a very considerable amount of inventive work and the state is rapidly approaching when the designing as well as the development and research engineer must be an accomplished mathematician.

In "Design of Machine Elements," Professor Spotts, while retaining a fundamentally practical outlook, brings in just enough theory to help the student appreciate that background of mathematics which gives the science of engineering its rational quality and an orderly pattern.

Although in a sense every chapter is complete in itself, so that the book can be studied in any order, the general arrangement of the work falls into three parts: The first gives a brief review of engineering theory and deals with the fundamental principles of stresses and classical assumptions on the physical behaviour of materials. The second and most important part of the book covers machine elements proper, and in particular, the theory and design of springs, screws, belts, brakes, and clutches; welded and riveted connections; ball and roller bearings; spur, helical, bevel, and worm gears, and a number of miscellaneous machine elements such as flywheels, gaskets, wire rope, hooks, and cams. A very useful addition to this section is a chapter on lubrication. The third and perhaps most valuable part in the book deals with design principles and engineering materials. The very important subject of tolerances is adequately covered and the characteristics, capabilities, and limitations of engineering metals are discussed, if somewhat briefly.

Many worked out examples are included as well as problems to be solved by the reader. A feature of the book is the excellent bibliography for further reading which gives the work the added advantage of a reference book. "Design of Machine Elements" is well written and extremely concise, contains much valuable information and, in giving the limitations of theoretical hypotheses, succeeds in marrying practice to theory in a manner which should prove most useful to student and designer.—M. D. J. BRISBY

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